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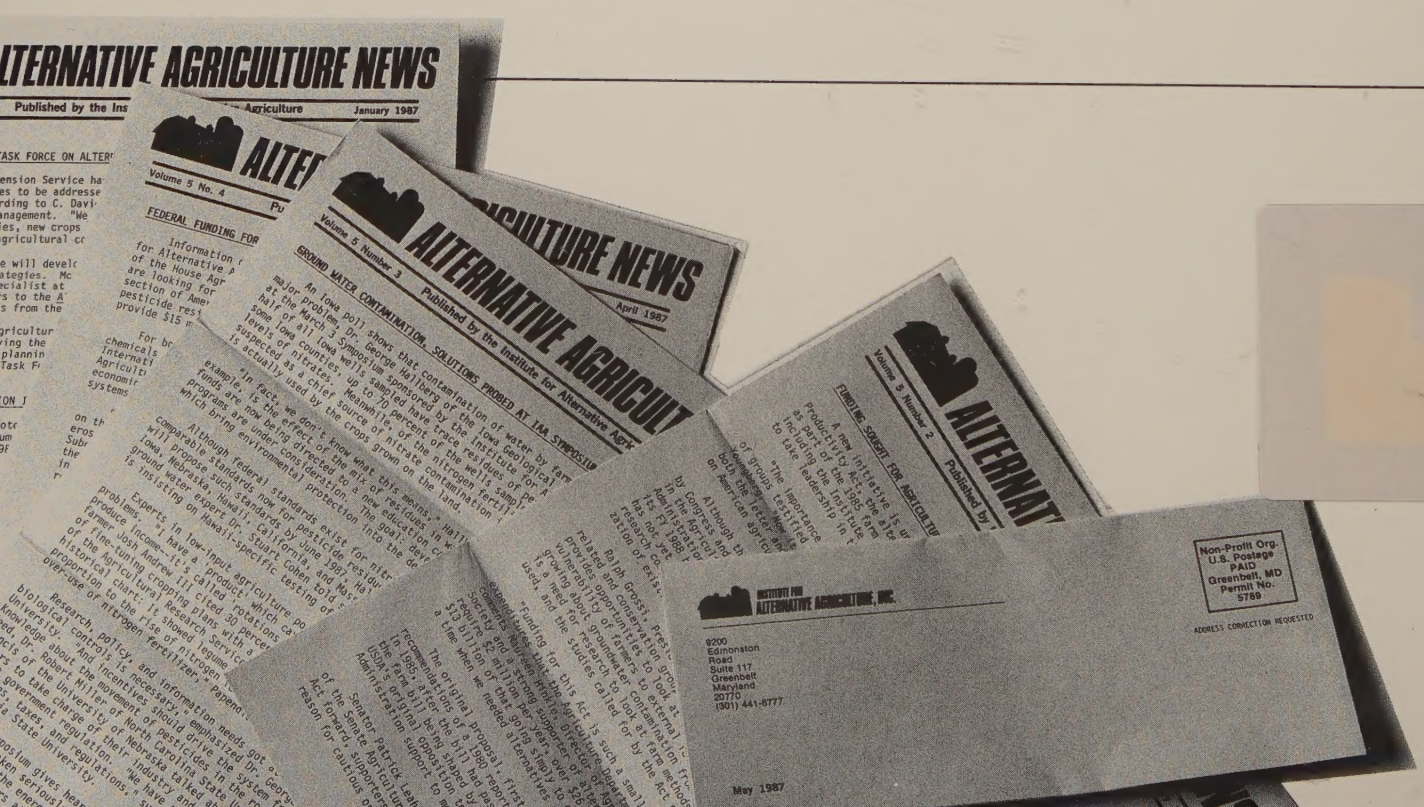
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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover photo is of *Olla v-nigrum* (mulsant), a principally-arboreal lady beetle which is believed to be important in controlling aphid pests of pecan, and which is often found in understory cover crops. Photo by Tom Girardeau, Tifton, Georgia.

Understory cover crops in pecan orchards: Possible management systems

Robert L. Bugg, Marianne Sarrantonio, James D. Dutcher, and Sharad C. Phatak

Abstract. *Annual legumes and mixtures of annual legumes and grasses can perform several functions as understory cover crops in pecan orchards, such as providing nitrogen-rich organic matter to improve soil fertility, or by sustaining lady beetles and other arthropods that may aid the biological control of pecan pests. Remaining questions concern selection of appropriate plant materials; whether to use cover crops singly or in mixtures; how to ensure reseeding as well as a substantial N contribution; whether, when, and how to use mowing and tillage; and fertilization options. Different considerations apply when dealing with cool- vs. warm-season cover crops. With minor adjustments, growers could adapt present cultural practices to include cool-season cover crops. These could be used throughout the orchard, by establishing appropriate self-reseeding species and avoiding both excessive mowing and indiscriminate placement of N-rich fertilizers. Within alleys, alternating 2-m strips of cool-season cover crops could be tilled in mid to late April or allowed to mature. The tilled strips would supply N to pecan trees immediately, whereas the adjoining untilled (remnant) strips could be mowed after seed is mature, to ensure dispersal of seed and reestablishment of cover crops over the entire alley. Cool-season annual legumes that die or are killed in late spring will probably furnish N and other nutrients at a suitable time, particularly in orchards with sprinkler irrigation. Warm-season cover crops, if desired, should be restricted to alleys to reduce possible competition with pecan. Alleys provide better illumination than do tree rows during periods when pecan trees are in leaf, and the tillage mentioned above will encourage emergence of warm-season cover crops. If these die or are killed in late summer or early fall, timing of N release may not be optimal, in the absence of adequate irrigation. Many options and tradeoffs need to be explored before choosing a cover-crop system. At times, several objectives may appear to conflict, and even delicately-managed mixtures of species may not fulfill all the desired functions.*

Key words: aphids, Aphididae, biological control, cover crops, Coccinellidae, Fabaceae, green manure crops, lady beetles, legumes, nutrient cycling

Introduction

Annual legumes or legume-grass mixtures were commonly grown as cover and green manure crops in orchard understories until the arrival of inexpensive synthetic nitrogen fertilizers during the 1940s and 1950s (Tedders, 1983). From the early 1960s through the late 1980s, little research was devoted to plants used for soil improvement (Hargrove and Frye, 1987). As a result, much of the literature on this topic antedates modern inferential statistics and is based on unreplicated studies. However, this situation is changing rapidly, with the depletion of petroleum reserves, the growing interest in sustainable agriculture, a the burgeoning science of agroecolo (see Power (ed.), 1987; Smith et al., 198 Allen and Van Dusen (eds.), 1988; Ha grove, 1991). There are many importa issues that must be addressed in adapti cover crops for use in orchards.

Forshey (1986), Skroch and Shrib (1986), Hogue and Neilsen (1987), a Lanini et al. (1988) have review orchard-understory management tec niques. According to these and other a counts, orchard cover crops present array of tradeoffs. Among their benefi cover crops can help increase soil N le els; improve availability of other nut ents, e.g., P (Gardner and Boundy, 198 and K (Hargrove, 1986); promote bett soil structure (Elliott et al., 1987); a sustain beneficial insects (Altieri a Letourneau, 1982; Bugg and Dutche 1989; Bugg et al., 1990a; Bugg et a 1991). On the other hand, orchard cov crops may compete with trees for wat or nutrients (Blackmon, 1948; Hard 1939); interfere with harvesting; harb stink bugs (Hemiptera: Pentatomida leaffooted bugs (Hemiptera: Coreida and plant bugs (Hemiptera: Mirida (Moznette et al., 1940; Dutcher a Todd, 1983; Bugg et al., 1990a,b); a perhaps divert beneficial insects by pr viding alternate prey at inopportu times (Bugg and Dutcher, 1989). proper selection and management cover crops, it may be possible to obta the benefits while minimizing detrime tal side effects. Our goal is to redu pesticide use and associated traffic a to improve soil structure and fertility addition of high-N organic matter, wh reducing reliance on synthetic fertilize This discussion, which is based in pa on the literature but which also enta considerable speculation, treats the p can orchard of southern Georgia as model system.

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The main crop: Pecan

Background

Pecan (*Carya illinoinensis* [Wangenheim] K. Koch, Juglandaceae) is a deciduous tree indigenous to temperate and subtropical North America; its native habitat is the deep alluvial soil adjoining rivers (Little, 1971). Grown for its flavorful nuts, it has been planted commercially within its native range from eastern Texas to western Alabama and north to southern Kansas. It also is grown commercially in Georgia, New Mexico, western Texas, Arizona, California, Canada, Australia, Brazil, Israel, Mexico, and South Africa (Harris, 1983). The principal pecan-producing state in the U.S. is Georgia, where from 40 to 50 percent of the U.S. crop is grown.

In Georgia, pecan phenology entails budbreak in mid March; catkins are produced and wind pollination occurs in early May, with shoot and leaf growth continuing through mid May; root growth takes place from mid April through September. Nuts develop through three stages: elongation, expansion, and kernel filling, from May through early October, when they are ready to be harvested (based on Ellis et al., 1984). Leaf drop typically occurs in mid November.

Current Practices

Georgian pecan orchards occur on a wide range of soils, including those of the Piedmont and Coastal Plain. Best growth occurs on deep soils with good moisture-holding capacity, as in soils with some sand or sand-loam texture with a clay subsoil. Trees are generally separated by from 8.5 to 17 m. Mature trees may attain a height of 42 m, and, depending on spacing, the understory may be in from 50 percent to 100 percent shade when trees are in leaf.

Pecan cultural practices are highly variable, but typically entail heavy applications of fertilizers, irrigation water, insecticides, fungicides, and herbicides, as well as mowing. In orchards with sprinkler irrigation, growers often try to simulate the native riparian habitat of pecan by applying sufficient water to compensate for evaporation, with as many as two irrigations per week during summer.

Management of soil fertility typically varies according to soil test or leaf analysis, as well as age of trees. In general, for medium-size trees (50 cm in trunk diameter), it is recommended that each tree receive at least 4.5 kg of N and 3.6 kg each of P and K (Crocker, 1982). Orchards with very large trees may require 112 to 140 kg N/ha (Worley, 1991, personal communication). Most or all of this need could be met by properly-managed leguminous cover crops.

Tree rows are typically contained within 3-m strips treated with herbicide to limit competition from understory vegetation. Alleys are generally devoted to mown grass, dominated by warm-season perennial sod-forming species, e.g., Bahia grass (*Paspalum notatum*), Bermuda grass (*Cynodon dactylon*), and centipede grass (*Eremochloa ophiuroides*). At harvest, pecans are mechanically shaken, swept into rows, and collected by three separate machines. Therefore, during late autumn, orchard floors must be smooth and relatively free of debris. The herbicide and autumn mowing help provide such conditions. However, growers typically mow during much of the year, a practice dictated largely by esthetics (Worley and Carter, 1973). Given sufficient moisture, the sod-forming grasses can recover rapidly following light tillage, but this practice is seldom used.

There are typically six fungicide sprays per season in the Southeast, principally to control pecan scab disease; none are applied in the arid growing regions of the southwestern U.S. and California. Insecticides are used to control pecan nut casebearer (*Acrobasis nuxvorella*), pecan weevil (*Curculio caryae*), hickory shuckworm (*Cydia caryana*), and aphids (Homoptera: Aphididae). There may be from one to seven insecticidal sprays per season, with a median of five. Three species of aphids attack pecan: yellow pecan aphid (*Monelliopsis pecanis*), blackmargined aphid (*Monellia caryella*), and black pecan aphid (*Melanocallis caryaefoliae*). Together, these are estimated to be the most damaging insect pests of pecan in Georgia (Ellis et al., 1988). Pecan aphids can be abundant even in unsprayed orchards from early May through June and August through early November, and they may erupt at other times as a result of sprays applied against other insects (Mizell and Schiffhauer, 1990). The situation has become particularly difficult with the development of insecticide resistance by pecan aphids (Dutcher and Htay, 1985).

Including mowing, pesticidal applications by ground rigs, and harvesting, pecan orchards may be exposed to 15 to 30 annual trips by heavy machinery, which may be expected to lead to soil compaction and accompanying reduced yields. In general, compaction is accentuated when heavy implements are used shortly after rainfall or irrigation (Håkansson et al., 1988).

Some pecan growers complain that current practices have led to soil compaction, reduced water infiltration, and frequent outbreaks of pests that may be exacerbated by control measures. For these reasons, some of these growers are looking once again toward the potential benefits afforded by cover crops.

The role of cover crops

Legumes were frequently used as cover crops in pecan orchards from 1920 until the 1950s, when inexpensive inorganic N fertilizers became available (see review by Tedders, 1983). During the 1920s and 1930s, both warm- and cool-season legumes were important. However, presumed though unproven competition for water by the former (White et al., 1981a) caused a shift toward exclusive use of the latter (Hardy, 1939; Blackmon, 1948). Competition for water by warm-season legumes may prove to be of little concern if water transpired by cover crops can be replaced inexpensively by irrigation. Currently, there is relatively little use of leguminous cover crops in pecan production, but interest in this practice is increasing.

Despite the many soil-improving functions of leguminous cover crops (White et al., 1981a,b), the immediate incentive for their use in pecan orchards may be enhancement of biological control of aphids. In intensively- managed orchards, the dominant cool- and warm-

Figure 1. *Sesbania exaltata* growing as warm-season understory cover crop in a pecan orchard. (Photograph by Robert L. Bugg).

season grasses rarely harbor aphids and seldom sustain aphidophagous lady beetles (Coleoptera: Coccinellidae). Cool-season cover crops can provide alternative prey (aphids and thrips [Thysanoptera: Thripidae] that are not themselves pests of pecan) that ensure reproduction or at least retention of lady beetles and other predators of aphids until pecan aphids become available in early May (Tedders, 1983; Bugg et al., 1990a; Bugg et al., 1991). Such cool-season legumes as hairy vetch (*Vicia villosa*) and crimson clover (*Trifolium incarnatum*), together with rye (*Secale cereale*), sustain aphids that do not attack pecans, along with associated lady beetles (e.g., convergent lady beetle [*Hippodamia convergens*], seven-spotted lady beetle [*Coccinella septempunctata*], and *Olla v-nigrum* [Cover Illustration]) that can disperse to pecan trees and attack pecan aphids. Cool-season cover crops are already being used by some pecan growers in efforts to enhance biological control of pecan aphids (Tedders, 1983).

Several winter-annual weeds that are common in pecan orchards can also harbor aphidophagous insects. For example, blackpod vetch or narrowleaf vetch (*Vicia sativa* ssp. *nigra* or *V. angustifolia*), lentil tare (*Vicia tetrasperma*), and low hop clover (*Trifolium campestre*) can harbor substantial densities of aphids and associated aphidophagous insects, whereas Virginia pepperweed (*Lepidium virginicum*) and chickweed (*Stellaria media*) provide flowers that are commonly used by adult aphidophagous hover flies (*Allograpta obliqua, Toxomerus* spp. [Diptera: Syrphidae]) (Bugg et al., 1991; R. L. Bugg, personal observation).

Warm-season legumes can also sustain aphidophagous insects. For example, sesbania (*Sesbania exaltata*) (Figure 1) often harbors cowpea aphid (*Aphi craccivora*) and bandedwinged whitefl (*Trialeurodes abutilonea*), and can sus tain lady beetles when pecan aphids ar scarce (Bugg and Dutcher, 1989). Unfor tunately, sesbania has the disadvantag of harboring high densities of variou stink bugs (R. L. Bugg, 1989, persona observation).

Despite the high densities of lady bee tles and other predators that often occu in understory cover crops, there is n published evidence that this leads to im proved biological control of peca aphids. For example, densities of aphid were similar in pecan trees with an without underlying summer cover crop of sesbania (R. L. Bugg and J. D Dutcher, unpublished data), or wit fall-planted mixtures of hairy vetch an rye (Bugg et al., 1991); in neither cas was there a major outbreak. There wa some evidence of increased densities o

convergent lady beetle in pecan trees with the undersown hairy vetch/rye mixture. Both the summer and winter trials were well replicated, but the spatial scale of the experiments (plot size and separation) may have been inadequate to show effects on the highly- mobile lady beetles.

In principal, cool-season cover crops may prove easier to use in enhancing biological control because they senesce and the associated predators disperse while pecan is becoming susceptible to aphid attack. In contrast, summer cover crops harbor abundant alternate prey while pecan aphids are active and might be expected to divert predators that would otherwise attack the target pests (Bugg and Dutcher, 1989). Therefore, simple management tools (e.g., mowing or tillage) may be needed to ensure timely dispersal of predators from warm-season cover crops to pecan foliage.

Management options and their consequences

Various options are available in the use of orchard-understory leguminous cover crops. The economic contribution of a cover crop results from its impact on soil N and other nutrients and organic matter; soil compaction and aggregate formation; soil biota, including decomposers and plant pathogens; weeds; beneficial and pest insects; and the economic crop (e.g., by competition, allelopathy, or facilitation). Performance of cover crops in these respects is affected both by choice of plant materials and by subsequent cultural practices.

Plant materials

Within a family as large and widely

Table 1. Properties of selected legumes suitable as cover crops in the understories of pecan groves.

Crop	Climatic/ Edaphic Tolerances[a]	Seasonality/ Growth Habit[a]	Phytomass (dry)[a], N Content[a] (kg/ha)	Agroecological Remarks[a]
Sesbania *Sesbania exaltata*	Tropic-warm temperate/ Moist, acid-neutral	Summer ann./ Erect	1,500[c], 65[c]	Cowpea aphid, bandedwinged whitefly, lady beetles[h] Supports vining legumes (e.g., velvet and hyacinth beans)[l] Sets seed early[c]
Florida velvetbean *Mucuna deeringiana*	Tropic-warm temperate/ Mesic-dry, acid-neutral	Summer ann./ Vine	5.900[f], 140[f]	Shade tolerant[m]; no stink bugs or leaffooted bugs[n]
Hairy indigo *Indigofera hirsuta*	Tropic-subtropic/ Mesic-dry, acid-neutral	Summer ann./ Erect	13,300[b], 220[b]	Cowpea aphid and lady beetles in autumn[h].
Showy Partridge Pea *Cassia fasciculata*	Mesic-dry, acid	Erect	7,173[f] 3,858-7,456[o], 79-145[o]	Reseeds without tillage[f], Harbors pea aphid[l]; extrafloral nectaries attract ants and parasitic and predatory wasps and flies.[p,g]
Narrow-leafed	Subtropic-warm temperate/	Winter ann./	5,000-7,500,	Low-alkaloid cv's have leaffooted bug, thrips, lady beetles.[i]
lupin *Lupinus angustifolius*	Moderately acid-neutral	Erect	250-450	
Spanish Lupin *Lupinus hispanicus ssp. bicolor*	Subtropic-cool temperate/ Acid-moderately basic	Winter ann./ Decumbent	6,000[g], 140[g]	Harbors few aphids or lady beetles, but some stink bugs.[l]
White sweetclover *Melilotus alba*	Subtropic-cool temperate Neutral to basic	Summer ann./bienn. Erect	9,000-10,500, 80-180	Biennial form has deep taproot, relieves soil compaction. Predatory wasps, parasitic flies use floral nectar[q]
Crimson clover *Trifolium incarnatum*	Subtropics-cool temperate/ Acid-neutral	Winter ann./ Erect	4,500-5,000, 170[e]	Pea aphid, blue alfalfa aphid, lady beetles.[j]
Subterranean clover *Trifolium subterraneum*	Subtropics-cool temperate/ Acid-moderately alkaline	Winter ann./ Decumbent	3,005-4,197, 150-207[d]	Indeterminate. Harbors aphids and lady beetles[i]; few *Lygus*[j,k]
Hairy vetch *Vicia villosa*	Warm to cool temperate/ Acid-neutral	Winter annual Vine	6,000-7,000, 150[e]	Late maturing (late May-early June)[l]. Harbors aphids, lady beetles[i,j]. Used with rye as mulch to suppress summer weeds[r].

[a] Where not otherwise noted, from Duke (1981).
[b] Baltensperger *et al.* (1985).
[c] Evans and Rotar (1987).
[d] F.A.O. (1984).
[e] Hargrove (1986).
[f] Reddy *et al.* (1986).
[g] Rodr Iguez-Kábana et al. (1988).
[h] Wells and Forbes (1982).
[i] Bugg and Dutcher (1989).
[j] Bugg et al. (1991).
[k] Bugg *et al.* (1990a).
[l] Bugg *et al.* (1990b)
[m] Bugg (pers. obs.).
[n] Bazil (1987).
[o] Moznette *et al.* (1940).
[p] Sarrantonio (unpubl. data).
[q] Boecklen (1984).
[r] Barton (1986).
[s] Luna and Rutherford (1989).

distributed as the Fabaceae, different plant species may have widely differing properties. It is important to have a grasp of the salient features of a plant and its potential agroecological role before incorporating it into a farming system. We have compiled summaries for several annual Fabaceae that could be used as cover crops in pecan orchards (Table 1). Such summaries can provide key information on potential uses and both physical and biotic constraints of available plant materials. Analogous information concerning various grasses (Poaceae) would also be useful but is not provided here.

In orchards that receive relatively few mowings or applications of N fertilizer, we often observe bahia grass, Bermuda grass, centipede grass, barnyard grass (*Echinochloa crusgalli*), large crab grass (*Digitaria sanguinalis*), crowsfoot grass (*Dactyloctenium aegyptum*), Florida pusley (*Richardia scabra*), and redroot pigweed (*Amaranthus retroflexus*). Thus, the understories are dominated during the warm season by perennial grasses and diverse annual weeds, but few summer legumes typically are present.

In such orchards, winter annuals include such grasses as rye, annual ryegrass (*Lolium multiflorum*), and such broadleafed weeds as Virginia pepperweed, Carolina geranium (*Geranium carolinianum*), chickweed, cutleaf eveningprimrose (*Oenothera laciniata*), and henbit (*Lamium amplexicaule*). The following cool-season annual legumes can be abundant: arrowleaf clover (*Trifolium vesiculosum*), blackpod vetch or narrowleaf vetch, buffalo clover (*Trifolium reflexum*), crimson clover, lentil tare, low hop clover, and southern or spotted burclover (*Medicago arabica*). These observations suggest that it may be relatively easy to encourage cool-season gumes in the pecan understory but m difficult to manage it for warm-sea legumes.

Monospecific vs. mixed cover crops

Cover crops may be grown in sin species or mixed stands. Mixtures m be more difficult to seed, harder to m age, and difficult to study, yet be risky under conditions of varia weather, soil, and sunlight (Kretschm 1974). Mixtures also might be expec to perform more functions while ploiting more agroecological nich Members of cool-season cover crop co plexes may perform complement roles.

For example, rye and hairy vetch often grown in combination, because erect rye provides structural support

Figure 2. A replicated small-plot study for evaluating cool-season cover crops and their associated insects. (Photograph by Sharad C. Phatak).

the vining vetch and may aid in weed control. Unlike most legumes, rye and other grasses produce masses of fine roots (Goldstein, 1989) that are efficient at scavenging soil N; legumes grown in mixtures with grasses typically obtain higher proportions of N by fixation (Mallarino and Wedin, 1990). Total amount of N fixed by legumes may be increased or reduced by the inclusion of grasses (West and Wedin, 1985). The fibrous root systems of grasses improve soil structure by stimulating soil microorganisms that exude gums that aggregate soil particles and by binding soil crumbs directly (Goldstein, 1989).

Studies in both small (Bugg et al., 1990a, Figure 2) and large plots (Bugg et al., 1991) indicate that a complex of cool-season plant species may provide a seasonal sequence of foods to lady beetles that might otherwise disperse from pecan orchards. For example, during late winter and early spring, rye sustains bird - cherry oat aphid (*Rhopalosiphum padi*), whereas hairy vetch later harbors abundant pea aphid (*Acyrthosiphon pisum*). These patterns are reflected in lady beetle abundance on these plants, whether grown in monocultures (Bugg et al., 1990a) or in mixtures (Bugg et al., 1991).

Members of warm-season cover crop complexes may also perform complementary roles. For example, a multispecific complex of warm-season legumes (Bugg and Dutcher, unpublished data, Figure 3) included Florida velvetbean (*Mucuna deeringiana*), hairy indigo (*Indigofera hirsuta*), hyacinth bean (*Lablab purpurea*), sesbania, and showy partridge pea (*Cassia fasciculata*), which have differing moisture, soil, and shade optima or tolerances. The complex developed a multi-tiered structure, with the relatively shade-tolerant hairy indigo and showy partridge pea at the lowest level, overtopped by the tall, erect sesbania plants, which in turn supported the vining Florida velvetbean and hyacinth bean.

Establishment and maintenance of cover crops

Because of the harvesting methods mentioned earlier, the perennial warm-season grasses that occupy the alleys are mowed closely during autumn. Under these conditions, most of the cool-season cover crops of interest can be seeded by no-till drills or by broadcasting seed and following with superficial tillage. Proper inoculation of legumes with the appropriate rhizobial cultures is essential, at least the first season that the legume is used.

Self-reseeding alone does not ensure reestablishment of a cover crop. Special cultural practices may prove essential. Many cool-season legumes (e.g., blackpod vetch, crimson clover, spotted bur

Figure 3. A multispecies complex of warm-season cover crops in a pecan orchard. (Photograph by Robert L. Bugg).

clover, subterranean clover) do not appear to require tillage to maintain good volunteer stands amid warm-season perennial sod-forming grasses. The autumn mowing in preparation for harvest probably facilitates reestablishment (Duke, 1981).

Seed of warm-season legumes may be broadcast or drilled, but disking or herbiciding of perennial grasses appears necessary to ensure establishment of most of the warm-season legumes we have assessed, the exceptions being showy partridge pea and hairy indigo (R. L. Bugg, 1989, personal observation). As mentioned, our observations suggest that, in neglected pecan orchards, volunteer summer legumes generally are scarce, but cool-season legumes are rather common. Few warm-season legumes occur in pecan orchards, even where mowing and application of N fertilizers have been curtailed. This may be due in part to competition from the abundant C-4 plants (species that use the Hatch-Slack photosynthetic pathway, e.g., bahia grass, barnyard grass, Bermuda grass, redroot pigweed). The Hatch-Slack photosynthetic pathway is regarded by physiological ecologists as advantageous under hot, dry conditions (Bannister, 1976).

Several approaches may assist in maintaining warm-season legumes against competing C-4 plants. It is important to establish summer legumes soon after the last threat of frost and before hot, dry weather. Shallow cultivation could temporarily reduce perennial grasses before the legumes are sown. Also, because drought might be expected to harm non-C-4 plants' abilities to compete, irrigation could be used when dry conditions prevail. Many pecan growers in southern Georgia use sprinkler irrigation once or twice per week. Warm-season annual legumes can usually be established under such a regime, so special irrigation may prove unnecessary. Two complementary options are the use of legumes selected for ability to withstand competition from C-4 plants, or use of grasses that are less competitive and therefore more compatible with desirable legumes (Short and Carlson, 1989). Selective or non-residual contact herbicides could also be used against grasses to improve the performance of warm-season legumes.

Alternatively, if warm-season perennial legumes are used (e.g., sericea lespedeza (*Lespedeza cuneata*) or alfalfa (*Medicago sativa*), these could be mowed periodically for green leaf manure or mulch, then allowed to regenerate.

Irrigation

Autumn irrigation may be desirable to ensure prompt establishment of cool-season cover crops. However, cover cropping does not necessarily increase the overall demand for water in orchard crops. For example, a cover crop of soft chess (*Bromus mollis*, cv 'Blando') has been shown not to increase the need for irrigation in Californian almond orchards and to improve water infiltration (Prichard et al., 1989). Perhaps similar results could be obtained with cool-season cover crops in Georgia. The use of cool-season cover crops to provide mulches that suppress warm-season weeds (as detailed below in the section on mowing and mulching) raises the possibility of "investing" some water in the autumn establishment phase in order to conserve water during spring and summer.

Choice of summer cover crops depends on soil type, drainage, and type of irrigation. Drought-intolerant species such as sesbania or American jointvetch (*Aeschynomene americana*) might be suitable only in moist, low-lying orchards or in orchards with sprinkler irrigation. Some researchers have suggested that it may not be advisable to use summer cover crops in unirrigated orchards because competition presumably could become important during July and August, when evapotranspiration rates are high and rainfall can be erratic (Blackmon, 1947). Assuming that the water supply is not limiting, use of irrigation may lessen concern about possible competition for water because it should enable the grower to better compensate for any water demanded by the legume. On the other hand, if cover crops are desired in well-drained, unirrigated orchards or those with drip systems or a limited supply of irrigation water, drought-tolerant species such as Florida velvetbean, hairy indigo, hyacinth bean, or showy p tridge pea could be used.

Overhead sprinkler irrigation of l umes can promote fungal epizootics a reduced populations of pea aphid (Pi ering et al., 1990), which in turn co lead to reduced densities of lady bee in the legumes. The implications for can aphids are not clear.

Maturation and reseeding of cov crops

When intended to supply N to the sociated cash crop, cover crops typica are mowed or incorporated at or ne peak flowering. This presents a potent conflict because it also would be des able for orchard cover crops to rese or, in the case of perennials, regrow, well as improve soil fertility. Approach to managing annual legumes could tailored to ensure reseeding while tyi up minimal N reserves in the seed ban Reseeding requires that a cover crop pr duce a substantial proportion of ha seed resistant to germination. If legum are not allowed to mature, but are kill or plowed down earlier, reseeding will prevented. On the other hand, if legum are allowed to mature, the ratio of C N will be higher and residue will ha more lignin (Gershuny and Smill 1986). Both conditions contribute slower decomposition and release of Moreover, in mature legumes, from to 90 percent of the N may reside in se (Anderson, 1866; Pate and Flinn, 19 Larson et al., 1989). In the absence "exportation" of seed by birds or dents, this N is in fact conserved in t system. However, the N sequestered seed is at least temporarily unavailal to the associated cash crop, which m cause a problem in the timing of relea Some Fabaceae produce copious quan ties of small seed, many of which so germinate, with most seedlings dyi shortly thereafter. In this case, much the N is soon converted to available in ganic forms. However, arrowleaf clo (cv 'Yuchi') and some varieties of cri son clover (e.g., cv 'Flame' [Balt sperger et al., 1987]) produce large p portions of hard seed, and N contain therein could be tied up for several yea

Reseeding and production of usable

could be obtained by plowing down strips of a cover crop at peak N content, generally at the early bloom stage, while permitting maturation in alternating remnant (reseeding) strips. Later rotary mowing of remnant strips could disperse seeds to tilled areas. Some legumes (e.g., blackpod vetch, Spanish lupin [*Lupinus hispanicus* ssp. *bicolor*], and hairy indigo) discharge seed forcibly to a distance of 2 m or more; mowing remnant strips to ensure seed dispersal should not be necessary with these species. In cases where sufficient hard seed is produced, remnant reseeding strips might only be required in alternate years. Width and distribution of remnant strips should be based on seed production per unit area of the species involved, the amount of seed required to sow the cover cropped area, and the seed dispersal obtained with various mowers. A northern Californian grower uses alternating tilled and remnant strips of 'Lana' vetch (*Vicia villosa* ssp. *dasycarpa*) in organic walnut orchards, based on estimates that about 10 percent of the cover crop (by area) should be allowed to mature for adequate reseeding of the entire orchard understory (Russell Lester and Mark Van Horn, 1991, personal communication). The effectiveness of this management scheme has yet to be fully evaluated.

An alternative approach would be to use indeterminate cover crops that retain substantial N in roots and shoots after producing seed. For example, the warm-season legume *Sesbania exaltata* produces mature seed well before full growth (Evans and Rotar, 1987) and could be disced after maturation of 20 percent of the seed. Seed are presumed mature when the pods turn brown. Among cool-season cover crops, certain subterranean clovers (*Trifolium brachycalycinum*, *T. subterraneum*, *T. yanninicum*) and various *Medicago* spp. and *Vicia* ssp. have indeterminate growth habits and might be managed similarly. It also may be possible to select for a combination of high seed yield and high leaf-matter yield in dual-purpose legumes (Akundabweni et al., 1990). These traits might be desirable for a reseeding cover crop. For cover crops that potentially can reseed, it would be helpful if researchers assess seed maturation and N allocation among vegetative and reproductive tissues at progressive stages of development to help in timing of mowing and tillage.

Mowing and mulching

As mentioned earlier, in conventional practice, alleys generally are devoted to mown grass; growers typically mow during spring, summer, and fall, as dictated by esthetics, without considering whether desirable legumes have matured seed. This practice probably eliminates many annual legumes while favoring perennial grasses such as bahia grass, Bermuda grass, or centipede grass. By removing developing seeds, improperly timed spring mowing may prevent desirable cool-season legumes from reseeding.

Apart from esthetic concerns, understory cover crops may be mowed to prepare for harvest, provide mulch, extend the lives of annual cover crops or weeds, force beneficial insects (e.g., lady beetles) into the pecan canopy in search of prey, or facilitate the establishment of winter-annual legumes in sods of warm-season perennial grasses. With cover crops of high biomass, mowing also may be advisable prior to tillage.

The prevailing shake-and-sweep harvesting procedure was developed to facilitate rapid nut removal and thereby reduce damage by rodents and spoilage fungi. It requires an orchard floor that is smooth and relatively free of debris. The method may reflect an undervaluation of proper soil management and may limit options for use of cover crops. Late-season harvesting can interfere with the early growth of cool-season legumes. On the other hand, harvest may limit the use of warm-season legumes because preparation of the orchard floor generally begins in late summer, and mowing may interfere with maturation of seed. However, legumes typically have lower C:N ratios than do the grasses presently used. Therefore, leguminous residues probably will degrade more rapidly than will grass residues upon mowing or incorporation into the soil (Waksman and Tenney, 1927; Jensen, 1929). Thus, if the warm-season understory vegetation is rich in legumes, perhaps mowing could be deferred until at least some seed has matured.

Perhaps the use of mats or nets that catch falling nuts could expand the range of choices; such approaches are now being explored in macadamia nut production in Queensland, Australia, and in Hawaii, where orchards of MacFarms International are being converted to organic production (J. Jodvalkis, 1988, personal communication).

Cover crops may be mowed and the residue moved from alleys into tree-row strips. Such a "mow-and-blow" approach could provide weed-suppressive mulch that may also encourage decomposer organisms, e.g., anecic earthworms, that enrich the soil. Properly timed mowing can increase biomass and N production by some legumes, as is the case with berseem clover (*Trifolium alexandrium*) (Williams et al., 1990; W. A. Williams, 1991, personal communication). Movement of the residue will also enhance regeneration of the mowed legumes and grasses. Side-discharge mowers that can deposit clippings within tree-row strips are now available commercially, including flail (G. Anderson, 1991, personal communication) and rotary types (Humus Maschinenfabrik, 1987; Whatley, 1987). This general approach has not been studied thoroughly yet, but is receiving increasing attention from growers, equipment manufacturers, and researchers alike.

At certain times, mowing may rejuvenate annual cover crops or weeds, postponing their maturation of seed and perhaps increasing the total amount of water they transpire. An important research priority would be to determine appropriate types of cover crops and mowing timing and heights to enable production of biomass and N, regeneration of the cover crops in the alleys to provide standing dead mulch, and reseeding, all with minimum water use.

Different types of mowers may be expected to have different effects on insects associated with cover crops, as described by Bugg and Ellis (1990). Sickle-bar mowers appear gentler and probably do less damage to lady beetles than do flail or rotary mowers. Also, height of mowing may prove important, but no comparative data are available.

Mowing of alternate strips may ensure

continuity of arthropod habitat through time. This approach has been used in alfalfa to retain western lygus bug (*Lygus hesperus*), a pest of cotton (Stern et al., 1967, 1969), and various predatory insects (Rakickas and Watson, 1974). Strip mowing might be expected to be similarly useful in retaining lady beetles that might depart from pecan orchards if cover crops mature uniformly. This idea has yet to be formally tested, but many orchardists and vineyardists in California now use the general approach (R. L. Bugg, 1991, personal observation).

Mulching can be attained with or without mowing. A mixture of hairy vetch and rye, if allowed to mature and left in place unmowed, apparently can suppress warm-season weeds, including perennial grasses, for several weeks into the summer (R. L. Bugg, 1989, personal observation; John France, 1990, personal communication). These observations are not surprising in light of the use of mowings from mixtures of hairy vetch and rye to provide weed-suppressive mulch (Luna and Rutherford, 1989) and the observations in forage trials that late-maturing cool-season legumes can suppress the yields of associated perennial warm-season grasses, e.g., Bermuda grass (Baltensperger et al., 1987).

The retarded breakdown of soil organic matter under no-till management can lead to soil biotic communities dominated by fungi and microarthropods (Hendrix et al., 1986), with anecic earthworms (Lumbricidae) as the dominant annelids, contributing to better soil structure (House and Parmelee, 1985; Parker, 1989). A no-till approach might lead to better rainfall infiltration (Glenn and Welker, 1989) and longer availability of habitat for beneficial insects (House and Alzugaray, 1989).

On the other hand, no-till systems may show increased N loss by ammonia volatilization (Terman, 1979; Sarrantonio, 1987); most studies have indicated that less N is made available from legumes under such regimes than with conventional tillage (Smith et al., 1987).

Tillage

Tillage is important in the management of cover crops because it ensures the prompt breakdown of residues and the release of N and other nutrients for use by cash crops. However, tillage is seldom used in pecan orchards because few growers rely on legume-derived N, and because disking may damage tree roots and the warm-season perennial grasses, and may cause soil compaction.

Plowing down cover crops may lead to quicker availability of N (Sarrantonio, 1987) but with an increased likelihood of nitrate leaching (House et al., 1984). Accelerated breakdown of organic matter could lead to soil biotic communities dominated by bacteria and protozoa (Hendrix et al., 1986), with Enchytraeidae being the principal annelids and an accompanying deterioration of soil structure (House and Parmelee, 1985). On the positive side, tillage can also destroy certain pests (e.g., hickory shuckworm) (Payne et al., 1975).

As mentioned in the section on mowing and mulching, there are benefits to no-till management of cover crops. Shallow cultivation may be a suitable compromise, with several benefits: some contact between residue and soil might facilitate microbial breakdown; seed will be incorporated; remaining surface residue will help maintain soil structure and permit surface-feeding earthworms to persist; little damage will be done to pecan roots, and sod-forming rhizomatous grasses can regenerate. The disk harrow is the most commonly used implement for such a purpose, and Wood and Wilson (1986) have shown that a one-time disking of alleys may raise pecan yields. However, cultivation with disk harrows is risky on the sandy soils of southern Georgia because soil that appears dry on the surface may be wet below a depth of a few centimeters. Tillage or vehicular traffic under these conditions can lead to compaction, which may be permanent on sandy soils (Håkansson et al., 1988). Studies on soils of the coastal plain of Georgia indicate that the disk harrow is among the most destructive tillage implements in compacting soil below the depth of operation (Phatak et al., 1981). Suitable alternative equipment that will reduce the threat of compaction include rolling cultivators, spring-tooth and spike-tooth harrows, the Aer-Way (Holland Hitch, undated), the "Groundhog Aerator" (Davies et al., 1989), ar power spaders.

Fertilizers and plant nutrition

Current recommendations for Geo gia are that fertilizers be applied duri February or early March, some s weeks before bud break, although son researchers now advise that mid-Marc may be better to avoid leaching loss before the trees become active (R. E. Worley, 1989, personal communic tion). Work in Californian almond o chards by Weinbaum et al. (1984) su gests that leaching loss of fertilizer may be particularly pronounced o sandy soils. Because spring growth of p can relies more on root reserves than o applied fertilizer, timing of N applicatio is less critical than in annual crops (E. E. Worley, 1989, personal communic tion). Hunter and Hammer (1947 working in non-irrigated orchard showed that time of fertilizer applicatio had no effect on pecan yield over a te year period. Those authors claimed tha during years of low rainfall, the percen age of well-filled nuts was lower whe fertilizer was applied during summer o fall; however, no inferential statistic were presented. Proper irrigation coul alleviate potential problems of untimel nutrient application. Winter-annual le gumes that die or are killed in late sprin would probably furnish N and other nu trients at a suitable time.

Properly-inoculated legumes usuall require little in the way of supplement N except, in some cases, during the earl stages of establishment, before nodul are formed. When soil N levels are rela tively low, legumes tend to fare better i competition with non-legumes. In fac when applied to mixtures of hairy vetc crimson clover, rye, and annual ryegras N fertilizers intended to fertilize the p can crop can seriously damage the tw legumes (by foliar burn) but increas growth of the grasses (R. L. Bugg, 198 personal observation). In many inte sively managed, heavily fertilized o chards, we have observed few volunte cool- or warm-season legumes.

We believe that pecan growers shou avoid direct application of N-rich fer lizers to established stands of desirab

legumes. On the other hand, it may prove useful to apply P, K, or S. Supplemental P can increase the shade tolerance of understory legumes, as has been shown for berseem clover used in an agroforestry system (Hazra and Tripathi, 1986).

Several issues relating to N are important to consider. In general, about half the N in a legume will become available the first year after it is incorporated, if there is no highly carbonaceous material tilled under as well. In the steady state for legume-based agroecosystems, the available soil N will be considerably higher than 50 percent of the legume N because soil organic matter releases nitrate and ammonium as it degrades. Orchards with large, mature pecan trees may require from 112 to 145 kg N/ha. If cool-season legumes are grown throughout the orchard and incorporated as green manure, they can contribute between 100 and 250 kg N/ha and thus in many cases could meet this need. If cover crops are restricted to alleys, the N contribution will be proportionally less. If remnant strips are retained for reseeding, or if the entire cover crop is managed by a no-till method, i.e., with residues left on the surface, a smaller fraction of N is likely to be available (McCalla and Russel, 1943; Dowdell and Cannel, 1975; Sarrantonio and Scott, 1988). N yields from legumes managed by the "mow-and-blow" approach have yet to be assessed. If supplemental N fertilizer is required to avert deficiency, it should be restricted to narrow bands beneath the trees and not broadcast indiscriminately onto legumes.

Suggestions for managing the pecan understory

Self-reseeding cool-season legumes, such as blackpod vetch, arrowleaf clover, crimson clover, or spotted medic, could be integrated easily into the conventional pecan-production system of southern Georgia. All that appears to be needed is the establishment of the relevant legumes and associated rhizobia, the avoidance of N fertilizers on the legumes, fertilization with non-N fertilizers as needed, and avoidance of spring mowing until legume seed has matured. Autumn mowing of warm-season grasses might be needed to ensure reestablishment. As mentioned, close mowing in autumn is already standard practice because of the harvest technique. Use of potent insectary cover crops like mixtures of hairy vetch and rye could be restricted to relatively few alleys and would require yearly reseeding. No-till seeders work well for this purpose.

A more ambitious goal would be to include both cool- and warm-season cover crops in the pecan production system. In Figure 4, we present such a scheme. We suggest that cool-season cover crops be used throughout the pecan orchard but that warm-season cover crops be restricted to alleys. Because pecan is deciduous, cool-season annuals in both tree-rows and alleys would receive adequate light throughout the winter. Although competition by summer legumes has not been shown to reduce pecan yields, such a reduction would be less likely if summer cover crops were restricted to the alleys. Cover crops in alleys would also receive more light when pecan trees are in leaf.

As mentioned earlier, 3-m strips of soil

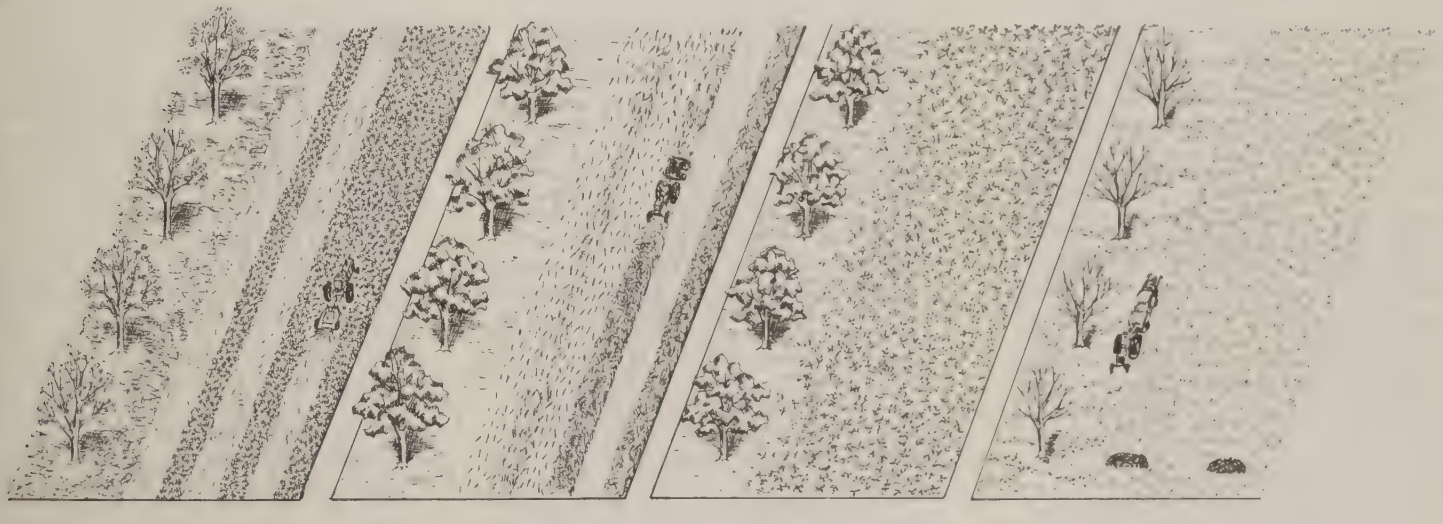

Figure 4. A scheme for year-round management of annual cover crops in the pecan orchard. (Illustration by Marianne Sarrantonio).
A. Mid to late April: Early maturing winter-annual legumes occur in tree rows; later-maturing species may be included in alleys. Alternating 2-m strips in alleys tilled or mowed for early N release. Remnant strips provide seed for reestablishing the crop next year.
B. Early June: Remnant strips mowed to disperse seed. Clippings deposited in tree-row strip. Entire alley tilled to incorporate residue and seed of winter annuals and prepare soil for reestablishment of summer-annual legumes.
C. Mid June to late September or early October: A multispecies complex of summer annual legumes grows in alleys, with sod-forming grasses included; leguminous vines extend into tree rows.
D. September to January: Understories are mowed in late September or early October; cover crop residue decomposes in place. Sod-forming grasses establish carpet for ease of harvest. Winter-annual legumes reestablish from late September to mid November.

occurring in tree-rows are typically treated with herbicide to reduce understory vegetation. Instead, tree-rows could be devoted to early maturing winter cover crops such as crimson clover or blackpod vetch. These will have mature seed by the time pecan is in full leaf and will compete little with the trees. With the coming of drier weather in late spring, any cool-season cover crops still growing vigorously in tree-row strips could be killed by non-residual contact herbicides, or they could be mowed, with the clippings left as a mulch to inhibit weeds. Mixed winter-annual cover crops, including such later-maturing types as hairy vetch, arrowleaf clover, subterranean clovers, and Spanish lupin, could be grown in the intervening alleys. Within the alleys, alternating 2-m strips could be tilled in mid-April or left to mature. The tilled strips would supply N to pecan trees, whereas the adjoining untilled strips would be mowed after seed is mature, to ensure dispersal of seed and reestablishment of cover crops over the entire alley. After the remnant strips have been mowed, the entire alleys could be tilled lightly in early June to incorporate seed of the winter cover crops and encourage emergence of summer cover crops.

Inclusion of vining species, such as Florida velvetbean, could lead to their running into the tree-row strips, over the dead mulch provided by winter cover crops, and limiting weed growth. Retention of sod-forming, warm-season grasses (e.g., common Bermuda grass) in polycultures with annual legumes and grasses will ensure that, when orchard floor vegetation is mowed to facilitate harvest, a suitable carpet of grass will be provided. Residue of summer cover crops could be left to decompose in place.

Conclusion

Cover crops clearly can be of great value in orchard understories, but many options and tradeoffs need to be explored before choosing a particular approach. Growers and researchers alike should develop broad agroecological perpsectives to appreciate better the ramifications of alternative approaches. The identification of suitable cover-cropping schemes for the pecan system may prove a complex task. At times, several objectives may conflict with one another, and even delicately-managed mixtures of species may not fulfill all the desired functions. In such cases, the grower should establish priorities. Other things being equal, any steps taken to reduce pesticide use, fertilizer applications, and traffic, while adding soil organic matter, can be counted as progress towards a more sustainable system.

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RESOURCES

Sustainable Agriculture Program of Minnesota--Greenbook 91 details the state's Energy and Sustainable Agriculture Program. Contact the Program, Minnesota Department of Agriculture, 90 West Plato Boulevard, St. Paul, MN 55107; (612) 296-7673.

Development of Conservation Farming on Hillslopes, a 332-page, hardcover book, provides models for successful cultivation of hillslope farmland. Single copies are available for $30 ($27 for members) from the Soil and Water Conservation Society, 7515 Northeast Ankeny Road, Ankeny, IA 50021-9764; 1-800-THE-SOIL.

Food from Dryland Gardens, a 387-page book, is an ecological, nutritional, and social approach to small-scale household food production in the industrial and Third Worlds. For information about costs, contact: Center for People, Food and Environment, 344 South Third Avenue, Tucson, AZ 85701; (602) 624-5379.

Industry Guide to New Jersey's Organic Markets/Consumer Guide to New Jersey's Organic Markets are published by Natural Organic Farmers Association of New Jersey and Stony Brook-Millstone Watershed Association. "Industry Guide" is $19.95; "Consumer Guide" is $8.95, from Stony Brook, 31 Titusmill Road, Pennington, NJ 08534; (609) 737-3735.

Sustainable Agriculture for California: A Guide to Information, a 196-page book published by the University of California Sustainable Agriculture Research and Education Program, U.C. Davis, is $12. Order Publication #3349 from U.C. Division of Agriculture and Natural Resources, 6701 San Pablo Avenue, Oakland, CA 94608; (415) 642-2431.

Managing Nitrogen for Groundwater Quality and Farm Profitability, a 378-page book published by the Soil Science Society of America, is $36 from SSSA Headquarters Office, Attn: Book Order Department, 677 South Segoe Road, Madison, WI 53711-1086.

Plant Breeding and Sustainable Agriculture: Considerations for Objectives and Methods, a 93-page softcover book published by the Crop Science Society of America and American Society of Agronomy, is $14 from CSSA, ASA Headquarters Office, Attn: Book Order Department, 677 South Segoe Road, Madison, WI 53711-1086.

1991 Washington Tilth Directory of Organic and Sustainable Foods and Services is $7.50 from Washington Tilth, P.O. Box 465, Olympia, WA 98507-0465; (509) 662-5545 or (206) 842-0722.

A new loan program for farmers who want to buy equipment for sustainable agriculture has been implemented by the Minnesota Department of Agricu ture, which will loan up to $15,000 6 percent interest. Contact: Sustainab Agriculture Loan Program, MDA, 9 West Plato Boulevard, St. Paul, M 55107; (612) 296-7673.

Farming for the Future: Resourc Packet includes information, newsle ters, and booklets compiled by th Northeast Organic and Sustainab Farmers Network. Send $15 payable NOFA Interstate Council to: Weste Massachusetts Agriculture Cente Marshall Hall, UMASS, Amherst, M 01003-0099; or call Karen Idoine, (41 545-4768.

Farmland for the Future--a Citizen Guide to Recreating the Food Syste is available for $2 from Land Steward ship Project, 14758 Ostlund Trail N Marine on St. Croix, MN 55047.

Good Earth Guide to Ohio Certified-Organic Farms and Garde is $3 from Ohio Ecological Food a Farm Association, 65 Plymouth Stree Plymouth, OH 44865.

1991 Sustainable Agriculture R source and Information Directory lis state and nationwide organization Contact Minnesota Department Agriculture, Energy and Sustainab Agriculture Program, 90 West Pla Boulevard, St. Paul, MN 55107; ca Linda Bougie, (612) 296-7673.

Sustainable swine production in the U.S. Corn Belt

Mark S. Honeyman

Abstract. *Swine production is a major component of Corn Belt agriculture; thus development of a sustainable Corn Belt agriculture depends on sustainable swine production systems. Swine are versatile enough to adapt to sustainable concepts, and swine production raises several opportunities to enhance sustainability. These include: 1) feeding with increased use of forages and by-product feeds; 2) nutrient cycling through improved handling of manure; 3) low-capital housing systems that offer an improved environment for the operator and reduced financial risk; 4) management systems suited to the swine's behavior; and 5) preventive approaches to swine health and a broader genetic base. The challenge beyond identifying the opportunities is research and technology transfer and incorporation of sustainable concepts into ecologically based swine production systems.*

Key words: sustainable agriculture, low-input livestock raising, manure, animal health, animal behavior, antibiotics, nutrient recycling

Introduction

Swine production is not usually given much attention in discussions of sustainable agriculture. Swine do not occupy large tracts of grazing land, and because they are not ruminants they do not use large amounts of fibrous forage crops. They do not seem to have much impact on ground water quality, soil conservation or the agroecosystem.

But on further investigation, it becomes apparent that swine production should be given major consideration in developing a sustainable agriculture in the U.S. Corn Belt. Swine production is a primary agricultural enterprise in this region, which produces about 70 percent of all U.S. swine (Iowa State University, 1988). Swine are major consumers of the region's leading crops, corn and soybean, which are converted into high-quality human food. Swine also generate a large quantity of manure. Except in metropolitan areas, the primary mammalian species in the Corn Belt is the domesticated swine.

In this paper I draw examples mainly from Iowa, but the discussion also applies to many other portions of the Corn Belt. Iowa has 14 to 15 million swine, about 3 million people, and 5 million cattle or about five swine per person and three swine per bovine. There is about .4 ha of corn and .2 ha of soybean per head of swine in Iowa. Swine production is an important part of the Iowa economy, generating $2 to $3 billion annually, or one-third of Iowa's cash farm income. Swine are present on 40 percent of Iowa farms (Iowa Department of Agriculture and Land Stewardship, 1989). The total swine/pork industry consists of 61,000 jobs, or 4.3 percent of Iowa's work force (Iowa State University, 1989).

If the goal of sustainable agriculture is to be economically profitable, more environmentally benign, and socially acceptable, the sustainable agriculture agenda in the Corn Belt clearly includes swine production. Sustainable swine production is a combination of production techniques that enhances profit and improves the area's environmental and socioeconomic conditions. To do this it must be integrated with appropriate cropping and human systems.

A sustainable swine production system should maintain or enhance the following areas over the long term:

the environment and the resource base;

the quality of life for producers and society as a whole;

producers' profits;

the quality of pork produced.

Ecologically sound swine production emphasizes intensive management of the swine and its entire environment. This means considering all aspects of the animal: its behavior, physiology, nutrition, breeding, health, and reproduction. It also means designing the system with the whole farm in mind, including its soil, topography, crops, other livestock, and operator. Finally, along with the swine, the farm and the producer, the consumer of pork also must be considered when the system is assembled.

The current situation

Historically, Corn Belt agriculture has achieved some sustainability through the advantages of a mixed-farming system originally developed in northwestern Europe in the Middle Ages and brought to America by European immigrants (Grigg, 1974). The mixed-farming system relies heavily on the integration of livestock production and raising of feed crops.

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The advantages of crop-livestock farming include: year-round employment for the farmer; diversification and integration of crop and livestock production; value-added livestock as the farm's major output; and nutrient cycling through manuring. Livestock production is the classic complement to feedgrain production (Figure 1), forming the traditional mixed-farming cycle.

The number of U.S. swine farms has dropped markedly since 1950. In Iowa, the leading swine-producing state since 1880, the number declined from 171 thousand in 1950 to 39 thousand in 1987. For the same period, the number of swine in Iowa has been fairly constant at 13 to 15 million. Therefore, the average number per farm in Iowa has increased steadily from less than 100 head in the 1950s to more than 350 head in 1987. This trend toward fewer but larger hog farms gives no indication of slowing (Futrell et al., 1988). Farms producing more than 1,000 head annually represented 13 percent of all producers and nearly half of all hogs marketed in Iowa in 1986. Nationally, farms producing more than 1,000 hogs annually accounted for 70 percent of all hogs marketed in 1986, with farms that produced more than 10,000 head accounting for 15 percent (Rhodes et al., 1987).

Sustainability issues

There are five interrelated areas in swine production that affect Corn Belt agriculture's sustainability. These feeding, manure utilization, housing, imal behavior, and genetics and heal

Swine feeding

In the Corn Belt, where the two le ing crops are corn and soybean, sw rations consist primarily of corn and s bean meal. In a description of Chin agriculture written in the early 1900s, H. King (1911, p. 122) wrote:

It is remarkable that these anci [Chinese] people came long ago to disc cattle as milk and meat producers; to sheep more for their pelts and wool th for food; while swine are the one kind the three classes which they retained the role of middleman as transformers

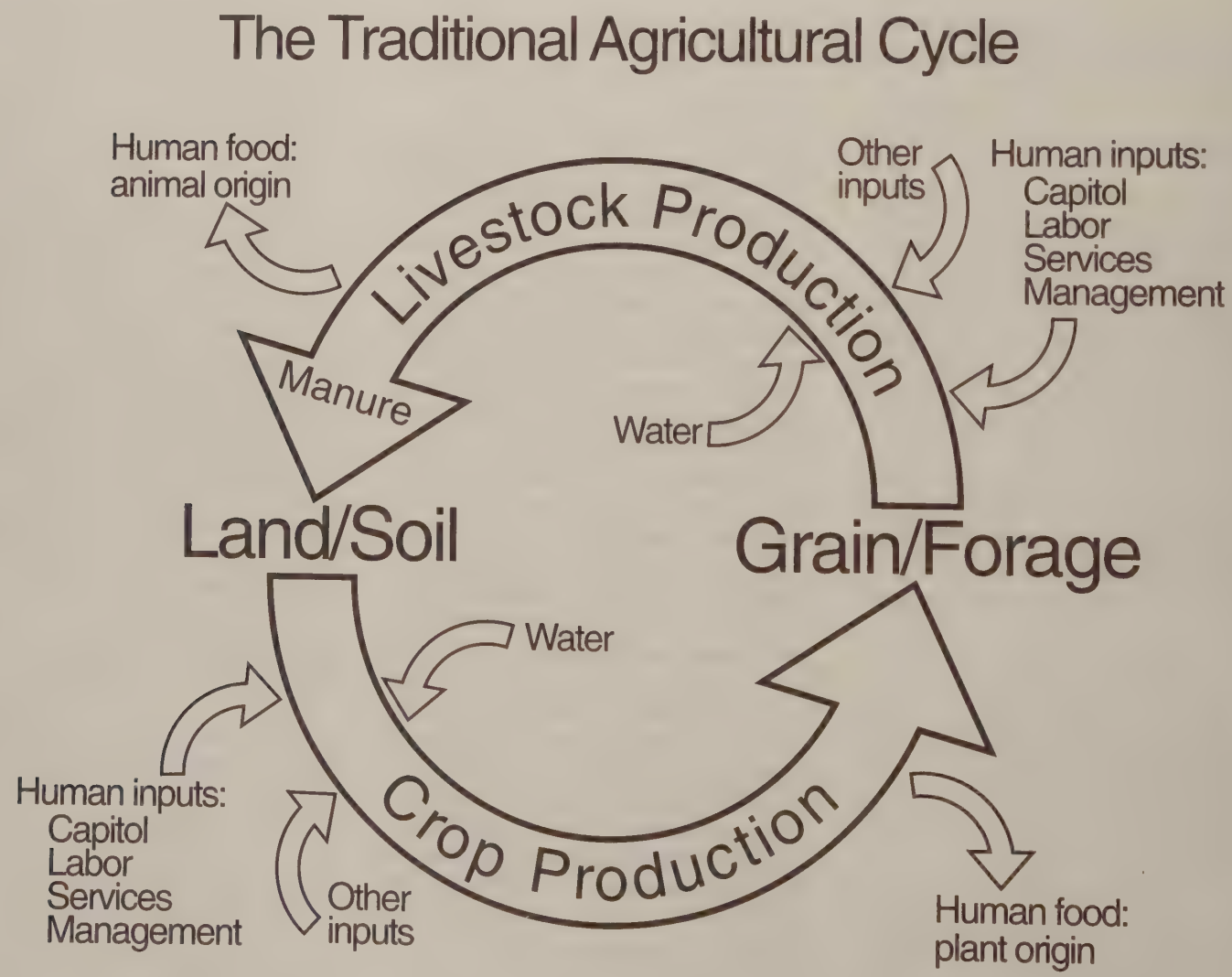

Figure 1. The Traditional Agricultural Cycle.

coarse substances into food.

Indeed, Corn Belt swine are such "middlemen," transforming feed grain and soybean meal into pork for human consumption. By changing the diet of Corn Belt swine, the face of Corn Belt agriculture can be changed, if economics and policies permit. As versatile omnivores, swine can utilize a wide range of feedstuffs.

Because of low energy needs relative to voluntary feed intake and a large digestive tract capacity, gestating sows are able to utilize fibrous feedstuffs quite well. Pond (1981) suggested that much more fibrous feed could be given to gestating sows. Reproductive performance was maintained or improved by high levels of alfalfa (Danielson and Noonan, 1975; Allee, 1976; Cuaron et al., 1979; Pollman et al., 1981; Calvert et al., 1985). Other fibrous feeds, forages, and by-products have been fed successfully to gestating sows. These include alfalfa-orchardgrass hay (Holzgraefe et al., 1986), alfalfa haylage (Wiesemuller, 1982; Hagen et al., 1987), sunflower hulls (Carter et al., 1987), soybean hulls (Kornegay, 1981), distillers dried grains with solubles (Thong et al., 1977), corn gluten feed (Honeyman and Zimmerman, 1990; Jones and Easter, 1987), grass silage (Livingstone and Fowler, 1984), and corn and cob meal, dried beet pulp, and wheat middlings (Zikovic and Bowland, 1970).

To a lesser degree, growing-finishing swine also can use fibrous feeds. Pond (1981) noted that growing swine can use fibrous feeds as 10 percent to 30 percent of the total diet if the energy level is maintained by including high-energy feedstuffs. The substitution rate depends on the extent of fiber lignification. Growing swine fed 20 percent alfalfa meal diets showed no change in gain or feed conversion compared to diets with no alfalfa (Kass et al., 1980).

Including alfalfa in a corn-soybean rotation is a way of making the rotation more sustainable. However, Corn Belt farmers considering this change are concerned about what to do with the alfalfa. Feeding it to swine is one possibility. For example, in 1978, forages accounted for 14.7 percent of all U.S. swine feeds (Council for Agricultural Science and Technology, 1980). Forages could be increased to 25 percent of the total diet required to produce market swine (96 percent for gestating sows) without major changes in production systems. This would reduce the amount of grain needed for swine production by 15 percent (Pond, 1981).

Assuming 20 million swine are marketed in Iowa annually, an increase of 50 kilograms of alfalfa per head (to double the current rate) would require an additional 150,000 ha of alfalfa, or 16 percent, assuming an alfalfa yield of 6725 kg/ha. On a hypothetical 160 ha Corn Belt farm that uses a corn-soybean rotation and produces 2,000 market swine annually with no forages, feeding alfalfa as 25 percent of the total swine diet (100 kg/head annually) would require 30 ha of alfalfa per year. Every hectare cropped would be in alfalfa once every 5 or 6 years. These changes would have very beneficial effects on water quality, soil erosion, and the use of fertilizer and pesticides.

The concept of by-product feeds is not new and is quite sustainable. Food processing and kitchen wastes (Gloridoss and Das, 1983) and even animal waste (Anthony, 1970; Bhattacharya and Taylor, 1975; Van Dyke et al., 1986) potentially are feeds for swine. By-product feeds can be more widely used in swine feeding, up to 20 percent of the total diet (Pond, 1981). Other sustainable alternatives for swine feeding include: using swine to harvest crops or crop residue, multi-species feeding systems, and use of low trypsin-inhibitor soybeans in swine diets.

A 40 to 60 percent reduction in feed grain use by swine is possible, without reducing performance, by substituting forages and milling by-products (Pond, 1981). The key to feeding swine in a sustainable system is utilizing feedstuffs that complement human activities (by-product feeds) and that are derived from crops that are beneficial for the environment (forages). The choices are based on relative prices and feed values of the competing feedstuffs. These choices must be made very carefully because feed accounts for about 60 percent of the total cost of producing swine and for 44 percent of the cost difference between low-cost and high-cost producers in Iowa from 1981 through 1987 (Hillburn et al., 1988). In the role of by-product and forage converter, swine can become much more compatible with humans, potentially even more so than ruminants.

Manure utilization

The Iowa swine population of 14 million head (Iowa Department of Agriculture and Land Stewardship, 1989) generates an estimated 15 to 18 million metric tons of manure annually, containing 105 to 123 million kg of N, 34 to 40 million kg of P, and 68 to 80 million kg of K (Midwest Plan Service, 1976). Distributed over the 4 million ha of corn (Iowa Department of Agriculture and Land Stewardship, 1989), this manure would contribute about 28 kg/ha of N, 18 kg/ha of K, and 9 kg/ha of P. This calculation allows for no nutrient losses and no additional nutrients from waste feed or bedding. Swine manure therefore is a significant resource, containing adequate nitrogen to supply the needs of 1 million ha of corn, or about one-fourth of the state's corn crop at 114 kg N/ha, again assuming no losses. In addition to its primary use as fertilizer, manure returns valuable organic matter to the soil, which builds soil structure and improves soil tilth. Also, manure can be a supplemental feedstuff and a valuable biomass energy resource. However, if swine manure is not properly stored, handled, and applied, nutrients can be lost, becoming major pollutants of air and surface and ground water.

In confinement operations, swine manure is highly recoverable, but only about 25 percent is economically recoverable (Van Dyne and Gilbertson, 1978). Higher energy and fertilizer costs and increased environmental concerns will make it more economical to recover manure. Various options are available to swine producers for managing manure (Midwest Plan Service, 1976). Manure management systems should include collection, handling, storage, transportation, and use of manure (Gilbertson et al., 1984). Losses, which in turn cause pollution, occur from leaching, volatilization and runoff (Sutton et al., 1990). These losses are common and high; loss

of N by volatilization can exceed 50 percent in 48 hours from surface applied manures (Hoff et al., 1981). In nonconfinement systems, the swine spread their own manure, and its value is captured through crop rotation.

An important difficulty in using manure as fertilizer is its variable nutrient and dry matter content. Another problem is adjustment of application equipment. Most manure spreaders that are currently available are built for rapid emptying and cannot apply manure uniformly at moderate rates. However, producers have not placed a high priority on proper calibration or distribution (Molnar and Wu, 1989).

Part of the manure utilization problem can be traced to larger swine production units with too little land to recycle manure nutrients appropriately. Regions with excess manure production have experienced degradation of surface water quality from runoff, high nitrate levels in shallow ground water, and high P levels in surface and ground waters (S. W. Melvin, Iowa State University, personal communication, 1991).

Using manure as fertilizer conserves energy. About 43 percent of the energy consumed in fertilizer manufacturing (N, P, and K) could be saved if all manure was more efficiently used. Swine manure could save about 11 percent of the energy used in fertilizer manufacturing, primarily N (Blouin and Davis, 1975).

As swine production facilities have become larger, the potential for odor and nuisances has grown. Adequate siting criteria are needed for planning and constructing swine production facilities. Siting criteria often are lacking or inadequate (S. W. Melvin, personal communication, 1991). Efficient manure storage systems for swine production units of all sizes need to be developed. Accurate and efficient manure application methods and equipment are needed to optimize nutrient recovery and minimize the chance of over-application (Gilbertson et al., 1984). In areas with high swine populations, including much of Iowa and the Corn Belt, water resources are at risk from losses of manure nutrients and organic matter. Crop and livestock production systems need to be matched to optimize the use of all resources, including manure (Sutton et al., 1990; S. W. Melvin, personal communication, 1991).

Manure management needs more research and technological development. Improved manure management is an excellent way to make agriculture more sustainable. With proper management, manure partially completes the nutrient cycle, but when improperly managed it becomes a pollutant, particularly in the livestock-dense Corn Belt.

Housing

Currently, swine housing is almost synonymous with swine confinement, that is, rearing swine in confined areas, usually indoors and often environmentally controlled. Precise data are not available, but most large-scale swine producers use confinement housing. The shift to confinement has been occurring rapidly in the last 30 to 35 years.

From 1973 to 1982, fixed costs (depreciation, taxes, and insurance) nearly doubled, from $1.94 to $3.80 per cwt. of swine marketed, according to the ISU Swine Enterprise Records (Mobley, 1987). Fixed costs accounted for 30 percent of the difference between high-profit and low-profit Iowa swine producers from 1981 through 1987 (Hillburn et al., 1988). Overall, the records indicate that "higher capital investment generally doesn't improve efficiency enough to offset increased production costs" (Mobley, 1987).

From a low-input viewpoint and perhaps to some degree from the sustainable viewpoint, confinement rearing of swine is not all positive. Economically, confinement feeding usually increases fixed costs, which inhibits the operation's flexibility, and supposedly reduces labor requirements.

Concerns are increasing about the air quality in confinement buildings. The University of Iowa's Institute of Agricultural Medicine and Occupational Health (Donham and Popendorf, 1985) measured hazardous gases in the air of confinement buildings on 21 Iowa swine farms. The mean concentrations (ppm) were: ammonia, 34; hydrogen sulfide, 1.4; carbon monoxide, 9.1; and carbon dioxide, 1640. Ammonia was most fr quently found in excess of the Thresho Limit Value, with farrowing and nurse units having the highest levels. The co bination of these gases and airborne du coupled with extended exposure (10 50 hours per week), may pose a signi cant health hazard to the 400,000 U swine production workers (Donham a Popendorf, 1985). Of the buildings su veyed, farrowing houses had the highe concentrations, except for carbon mo oxide. Farrowing requires the most lab of any phase of production so that t concentrations to which producers a exposed are greater than the means giv above.

After reviewing several studies r ported in the late 1960s and early 197 by experiment stations in Indiana, Il nois, and Nebraska, Curtis (1983) fou no major differences in Corn Belt swi performance (gain and feed efficienc between "environmentally regulate swine housing and housing open to t outside. He concluded that the choi of housing was based on the operato personal preference, not the improv performance or health of the anima The move to confinement is a perceiv substitution of capital for labor. Furth more, the producer avoids the weath and predator risks of a nonconfineme system but takes on the increased fina cial and personal health risks of a co finement system.

There are reasonable alternatives confinement swine production. So Corn Belt producers successfully farr and rear swine on pasture during warm months. Sows farrow on pasture in in vidual huts, and the swine either are f to market weight on pasture or mov to more confined areas for feeding. Tr ditionally, this system of pasture reari of swine has been viewed as involvi high labor, low cost, and often low ma agement. When coupled with intensi management, pasture rearing of swine a profitable alternative to confineme and warrants closer examination. Ma successful low-input swine enterpris have been documented in the popul agricultural press (Johnston, 198 Phelps, 1986; Russell, 1987, 1990; Wa kins, 1987; Houghton, 1988; Marber 1988).

Many confinement systems were built during the inflationary 1970s when inflated asset values were leveraged to pay for new construction, and labor costs increased faster than the cost of capital. The 1980s saw an almost complete reversal of this economic situation, and a "pay-as-you-go" attitude prevailed. Inaccurate estimates of repair costs (too low) and of the life of structures and equipment (too long) encouraged confinement construction. The useful life of confinement facilities often is 5 to 7 years, rather than the 15 to 20 year estimate commonly used in cost calculations during the 1970s. These costs raise the total cost of production dramatically. Additionally, the labor savings often were overestimated.

A closer comparison of pasture rearing to confinement leads to the following conclusions (Kliebenstein and Sleper, 1980; Lidvall et al., 1980; Kliebenstein et al., 1981; Carnell, 1983; Killingsworth and Kliebenstein, 1984; Cantrell, 1985; National Research Council, 1989):

1) similar weight gain and feed efficiency;

2) similar feed costs, but bedding is needed for pasture rearing;

3) lower initial and annual costs for capital improvements in pasture systems;

4) somewhat higher labor costs for pasture systems--but often not as large as expected and no greater than the differences among individual farms;

5) similar sow reproductive performance (somewhat dependent on weather);

6) reduced animal health problems on pasture, particularly respiratory diseases, rhinitis, and leg-soundness problems, but greater potential for parasite problems;

7) possibility of year-round production in confinement;

8) higher heating, cooling, and ventilation costs for confinement systems;

9) fewer odor problems in well-managed nonconfinement systems.

These comparisons suggest that swine production can be profitable and more sustainable using systems that are not dependent on confinement. Low-input sustainable swine production systems may be particularly well suited for marginal lands in the Corn Belt. A simple approach would be to crop the ridges and bottomlands intensively, since these soils usually are the most fertile and the least susceptible to erosion. The fragile, highly erodible side slopes could be put in a four-year rotation of corn, oats, alfalfa, and pasture swine production. This would reduce erosion and build organic matter on the eroded slopes and provide on-farm employment and low-capital development to regions that are economically depressed. This system is a much more sustainable approach than the USDA Conservation Reserve Program, which provides no employment, or the traditional Corn Belt beef cow herd, which requires low labor and high capital but generates low returns. In addition, small low-input sustainable swine operations can be excellent supplementary enterprises and sources of employment in rural areas.

Animal behavior and management

An emerging issue in livestock production, including swine, involves the principles of animal behavior and welfare. In Europe, animal welfare laws are changing the way swine are raised, for example, making sow tethering and gestation crates illegal. In the Corn Belt, animal welfare efforts generally have not yet had any effects, but there is growing awareness of them. For example, in Minnesota, producers are test producing and marketing pork endorsed by the Animal Welfare Institute (AWI) (Miller, 1989). AWI's goal is to "encourage farmers to rear swine in a more humane way" and to phase out very intensive production methods. The AWI pork label will claim that the swine are produced by family farmers, are free to move about, and have received no subtherapeutic drugs. Farrowing will be in pens or on pasture (Miller, 1989).

Certainly, swine production could benefit from researchers doing more studies of movement and behavior and then altering the production system to use the animal's behavior to advantage. A recent example is the work in Illinois that used videotape to study how swine eat from various commercially available feeders. The feeders were rated on waste, obstructions, and design. The researchers then designed an improved feeder that is now being manufactured (Taylor and Curtis, 1988, 1989).

However, the animal welfare issue is much broader than this; in an evaluation of intensive animal agriculture, Curtis (1987) concluded that livestock producers face an "animal-welfare dilemma." The producer must choose a production system that meets not only the demands of profit, but also the producers' and the public's humane concerns and the demands for safe food and a clean environment. These forces--economic, environmental, and humane--may conflict, so that compromise among them is necessary. The more favorable the economics, the more rapidly the appropriate technology will be adopted.

In an ecological model of swine production, the pig's behavior and physiology should be a central part of the system, rather than something to be overridden with equipment, drugs, or other constraints. The challenge of sustainable swine production is to identify and build innovative systems that incorporate the animal's innate behavior.

Genetics and health

The genetic base of U.S. swine is fairly narrow. Eight primary breeds make up most of the population, with three or four breeds the predominant ones. The last significant imported breed was the Landrace, brought from Europe in the 1950s. However, under a recent cooperative agreement, Iowa State University, the University of Illinois, and USDA recently have imported three Chinese breeds of swine--Meishan, Fengjing, and Minzhu. Of particular interest are their traits of prolificacy, early puberty, intramuscular fat, finer meat quality, increased fiber digestion, greater cold tolerance, and improved disease resistance (Zhang et al., 1983). Unfortunately, the breeds also are slow growing and very fat. The Chinese traits have implications for sustainable U.S. swine production. Potentially, the breeds will diversify the U.S. swine population by broadening its genetic base, which increases the potential for gains in performance under varied production environments.

Improved disease resistance would be

a great advantage. Swine health is a major challenge for producers and the industry. Some major diseases have been eradicated in the United States (e.g., hog cholera), and eradication of others is in the planning stage (e.g., pseudorabies). In confinement, health problems can become intensified because of the higher swine density. In a Missouri survey of swine producers during 1978 and 1979, one-third of the swine had been affected by health problems (Kliebenstein et al., 1983). Producers who used pastures had the lowest swine health expenses. Expenses increased with increasing confinement. However, producers using a mix of facilities had the highest expenses, which suggests that swine may have difficulty adjusting from one production system to another (Kliebenstein et al., 1983).

A controversial area in swine health has been the use of antibiotics, particularly at subtherapeutic levels to prevent disease, promote growth, and improve feed efficiency. About three-fourths of U.S. swine receive antibiotics at some time in their lives (Hays et al., 1986). Antibiotic use for livestock has increased dramatically (Figure 2) because it is profitable (National Research Council, 1989). No definitive scientific conclusions have been reached in the controversy over whether bacterial resistance to antibiotics induced by feeding antibiotics to livestock is transmitted to human pathogens (Council for Agricultural Science and Technology, 1981; Hays et al., 1986). However, some scientists and members of the public perceive a potential human health risk from widespread use, and at times misuse, of antibiotics in livestock production (Office of Technology Assessment, 1979; Institute of Medicine, 1989). This debate no doubt will continue because of the current emphasis on health and food safety.

In sustainable swine production, pr ority should be given to prevention ar disease eradication, rather than on di ease treatment. The economic incentiv and public pressure for this swine healt agenda will increase.

Summary

Clearly, profitable and environme tally sound swine production systems a critical for a sustainable agriculture the U.S. Corn Belt. Several issues emer when conventional swine productio systems are examined with regard their sustainability. We need innovativ thoughtful alternatives to prevale practices in swine production, includin the corn-soybean meal diet, intensiv confinement systems, and handling manure as a waste rather than a r

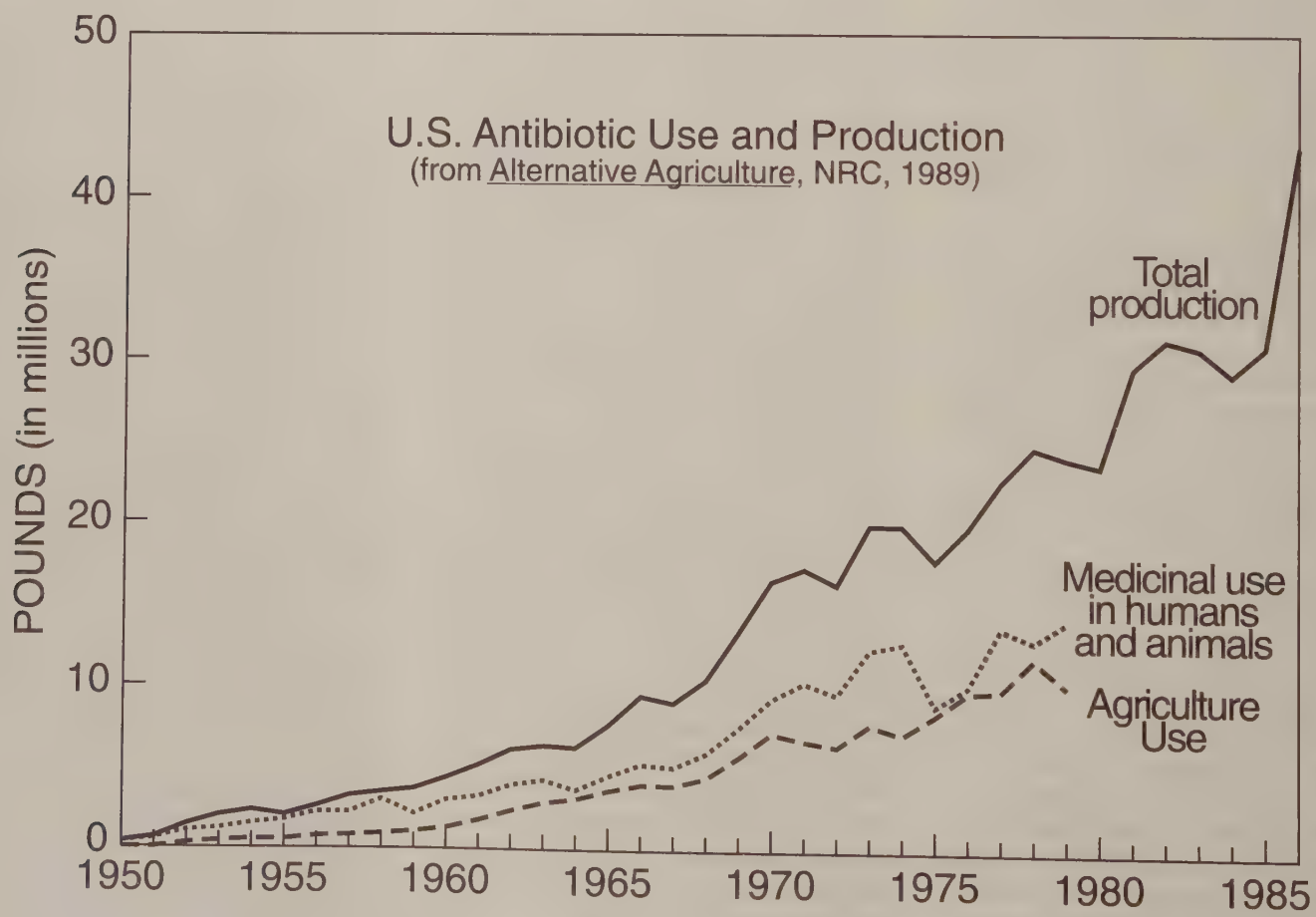

Figure 2. U.S. antibiotic use and production (from *Alternative Agriculture*, NRC, 1989).

source. Feeding, housing, and manure utilization are major factors in the profitability and environmental impact of swine production. Feed cost and fixed costs (which depend on the housing system) are the two leading determinants of swine production profits in Iowa, accounting for 74 percent of the difference between the state's high-profit and low-profit producers from 1981 through 1987 (Hillburn et al., 1988). Manure is a major by-product of swine production in the swine-dense Corn Belt and has great potential for polluting air, water, and soil if mismanaged. Yet it also is the key to nutrient cycling and sustainability if it is managed appropriately.

The suggested alternatives are management driven rather than production driven; that is, they must be coupled with intensive management to become fully successful. The ecology and biology of the swine must be incorporated into sustainable production systems, and the farm's other crop and animal enterprises need to be closely integrated with the swine enterprise. The sustainable alternatives discussed here do not mean returning to antiquated production systems of the past. Rather, they mean selecting the appropriate technologies and combining them into management-intensive systems that are closely coupled with other livestock activities and crop production in a customized way to optimize the output from a given set of soil, plant, animal, and human resources.

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UPCOMING EVENTS

November 15-17. Farmer-to-Farmer Conference, sponsored by the Maine Organic Farmers and Gardeners Association, will be held at the University of Maine at Orono. Contact the Association, P.O. Box 2176, Augusta, ME 04338; (207) 622-3118.

November 19. Sustainable Agriculture Conference, sponsored by South Dakota State University, will be held in Brookings, South Dakota. Contact David Becker, SDSU Economics Department, Brookings, SD 57007-0895; (605) 688-4877.

November 19. Tools for Building A Sustainable Agriculture: Neighbor Teaching Neighbor, sponsored by the Kerr Center for Sustainable Agriculture, will be held at the Robinson Center, Little Rock, Arkansas. Contact Gail Lee, Arkansas Cooperative Extension Service, P.O. Box 391, Little Rock, AR 72203; (501) 671-2173.

November 21-22. Conference on Innovative Policies for Agricultural Research, sponsored by Tufts University, will address needed changes in professional and institutional settings for conduct of alternative agriculture research. The conference will be held at the Lenox Hotel, Boston, Massachusetts. Contact William Lockeretz, School of Nutrition, Tufts University, Medford, MA 02155; (617) 391-1033.

December 2-4. Acres U.S.A. 1991 Conference will be held at the Hilton Airport Plaza Inn, Kansas City, Missouri. Contact Acres, P.O. Box 9547, Kansas City, MO 64133; (816) 737-0064.

January 22-23, 1992. Organic '92, sponsored by the University of California Small Farm Center and the Committee for Sustainable Agriculture, will be held at Asilomar Conference Center, California. Contact the Center, University of California, Davis, CA 95616; (916) 757-8910.

January 23-25. 12th Annual Eco-Farm Conference, sponsored by the Committee for Sustainable Agriculture, will be held at the Asilomar Co ference Center, Monterey, Californi Contact the Committee, (91 346-2777.

January 31-February 2. Winter Co ference, sponsored by the Norther Plains Sustainable Agriculture Societ will be held at the Holiday Inn in Bi marck, North Dakota. Contact the S ciety, Box 36, Maida, ND 58255; (70 256-2424.

February 6-9. Second Global Stru tures Convocation: Environment an Development will be held at the J. W Marriott Hotel, Washington, DC. Co tact Joan L. McKinney, Convocatio Director, 418 - 7th Street, SE, Wash ington, DC 20003; (202) 546-3950.

February 7-9. California Farm Co ference '92, sponsored by Californi Department of Food and Agricultur and several farmers' associations, wi be held in Santa Rosa, California. Co tact Carl DeWing, CDFA, 1220 Street, Sacramento, CA 95814; (91 445-8614.

February 9-14. Annual Meeting the International Society of Rang Management will be held in Spokan Washington. Contact Carl J. Goebe Natural Resources Sciences, Washin ton State University, Pullman, W 99164; (509) 335-8570.

February 13-15. Fourth Nation Conference on Organic/Sustainab Agriculture Policies, sponsored by th Center for Science in the Public Inte est and the IAA, will be held at th Hyatt Regency Hotel, Bethesda, Mar land. Contact Agriculture Conferenc CSPI, 1875 Connecticut Avenue, NW #300, Washington, DC 20009-5728.

March 2-3. IAA's 9th Annual Co ference, "Alternative Farming Syste and Rural Communities: Exploring th Connections," will be held at the Na tional 4-H Center, Bethesda, Mar land. Contact the IAA, 9200 Edmon ton Road, Greenbelt, MD 20770; (30 441-8777.

Cover crop management effects on soybean and corn growth and nitrogen dynamics in an on-farm study

D. L. Karlen and J. W. Doran

Abstract. *Combining cover crops and conservation tillage may result in more sustainable agricultural production practices. Objectives of this on-farm study were to quantify effects of cover crops on growth and nitrogen accumulation by soybean [*Glycine max *(L.) Merr.] and corn (*Zea mays *L.) on a Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludoll) near Boone, Iowa. Our farmer-cooperator planted soybean in 1988 using ridge tillage into an undisturbed strip with a hairy vetch (*Vicia villosa *L. Roth) cover crop and into a strip where previous crop residue and a negligible amount of cover crop had been incorporated by autumn and spring disking. In each strip, we established four plots for soil and plant measurements. Our cooperator planted corn on the same strips in 1989 into a cover crop that consisted of both hairy vetch and winter rye (*Secale cereale *L.). We determined the source of N accumulated by the corn by applying 67 kg N/ha of* ^{15}N *depleted* NH_4NO_3 *fertilizer. In the absence of cover crops, early season soil* NO_3*-N levels in the top 30 cm were higher, and corn growth and N accumulation were more rapid. At harvest, the corn grain, stover, and cob together accounted for 36 and 39 percent of the* ^{15}N *fertilizer for the ridge tillage and disked treatments, respectively. We suggest that lower net mineralization of organic matter or greater denitrification losses before planting reduced the availability of soil N. This created an early season N stress in corn grown with cover crops that was not overcome by broadcast fertilizer N applied three weeks after planting. Our on-farm research study has helped focus continuing efforts to determine if non-recovered fertilizer N is being immobilized in microbial biomass, lost by denitrification, or leached below the plant root zone.*

Key words: *Zea mays, Glycine max.*, hairy vetch, *Vicia villosa* (L.) Roth, nitrogen use efficiency, ridge tillage, disk tillage

Introduction

Innovative farming methods must be implemented to reduce soil erosion and improve N use efficiency. New practices are needed because soil erosion, estimated to be as high as 22 Mg ha^{-1} $yr.$ from cropland in Iowa (Soil Conservation Service, undated), N leaching (Hallberg, 1989a; Keeney, 1989), and pesticide contamination of water resources (Hallberg, 1989b) are problems threatening the sustainability of American agriculture. Larson et al. (eds., 1990) state that erosion, soil productivity, and water quality issues are related and must be addressed for civilization to continue. However, long-term declines in soil productivity from soil erosion are difficult to document because improved germplasm and increased fertilizer rates (especially N) often mask gradual productivity declines (Mannering et al., 1985).

In Iowa, a corn-soybean rotation generally results in higher grain yields for both crops (Voss and Shrader, 1988) because of reduced disease and insect pressures. However, soil erosion losses with this rotation are greater than losses from continuous corn (Laflen and Moldenhauer, 1979). Erosion losses are greater with soybean in the rotation because residues are quickly lost following harvest and soil is exposed to direct raindrop impact. McCracken et al. (1985) reported that soybean cropping decreased aggregate stability, resulting in dispersion and transport of soil particles. As management alternatives for reducing surface sealing and soil erosion, they suggested using no tillage, double cropping with winter grain, planting crops on the contour, growing crops with a good canopy, and leaving the soil covered with residue from the previous crop.

Two farming practices that will reduce soil erosion and that may improve N use efficiency for a corn-soybean rotation are conservation tillage and use of cover crops. These practices reduce soil erosion by increasing surface cover, adding organic matter, and functioning as catch crops for residual nitrate nitrogen (Frye et al., 1988). Cover crops and conservation tillage may also be useful for improving soil tilth (Karlen et al., 1990).

In New York, central and northern Illinois, Iowa, and for continuous corn on poorly drained soils in Indiana and Ohio, low soil temperature was reported as a major limitation for the no-till form of conservation tillage (Karlen, 1990). Development of ridge tillage techniques

Contribution of the USDA-ARS.

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is helping to solve the problem of cold soil in many states (Gupta et al., 1983); but if rainfall and soil water content are low, ridges may become too dry for optimum emergence and seedling growth.

Using non-legume and legume cover crops to provide surface soil cover, reduce fertilizer N use and costs, control soil erosion, and slow leaching of residual NO_3-N are not new ideas (Pieters and McKee, 1938; Smith et al., 1987). However, farmer interest in cover crops has increased as more people evaluate alternative cropping practices. Recent reviews by Wagger and Mengel (1988) and Frye et al. (1988) have discussed how cover crops affect efficient use of water and nutrients. For example, a winter cover crop effectively limited NO_3-N leaching in southern (Karraker et al., 1950) and northern (Bertilsson, 1988) regions.

According to Wagger and Mengel (1988), the quantitative effects of non-legume cover crops on soil organic carbon, runoff, infiltration, water storage, and N use efficiency are unknown. For legume cover crops, preliminary studies have shown satisfactory performance by hairy vetch as far north as central New York (Scott and Burt, 1985), but low winter temperatures generally limit their use in conservation tillage systems further north than southern Ohio and Pennsylvania. Improving or selecting cover crop germplasm that can tolerate more northern conditions has been identified as an important research need by several authors (Power (ed.) 1987; Frye et al., 1988).

Winter rye and Italian ryegrass (*Lolium perenne* L.) are very effective cover crops for reducing leaching losses of residual nitrogen (Brinsfield et al., 1988; Staver and Brinsfield, 1990; Martinez and Guiraud, 1990). A disadvantage of a winter rye cover crop is that it can be very aggressive during the following spring, depleting available soil water supplies and thus stressing the primary crop. This has been reported for sandy soils in the southeastern U.S. (Campbell et al., 1984) and observed in on-farm experimentation in Iowa (R. L. Thompson, personal communication, 1990). The use of oats (*Avena sativa* L.) instead of rye as a cover crop is currently being evaluated in Iowa, since it grows rapidly during autumn but freezes in winter and therefore does not deplete soil water reserves in spring (T. C. Kaspar, personal communication, 1990). Oats also provide an excellent companion crop for hairy vetch when broadcast into scenescing soybean in Iowa (R. L. Thompson, personal communication, 1990).

In general, cover crops have not been widely accepted by farmers because of potential agronomic problems that may lower yields and profits from their primary grain crops. The need for additional management and perceived expenses are also given as reasons for not growing cover crops. Typical problems include depletion of seedbed water (Karlen, 1989), loss of N through immobilization or denitrification (Doran et al., 1989), reduced soil temperature (Gupta et al., 1983), and possible production of allelopathic compounds (Anderson et al., 1988; Martin et al., 1990). In this study, our objectives were to quantify cover crop effects on soybean and corn growth and aerial N accumulation in an on-farm research study where the farmer-cooperator was generally successful and pleased with his cover crop management practices.

Methods and materials

We conducted on-farm field research (Rzewnicki et al., 1988) in 1988 and 1989 on Nicollet loam at the Richard and Sharon Thompson farm near Boone, Iowa. Our experimental site had 0 to 2 percent slope but was adjacent to an area with a 9 to 14 percent slope. The initial soil characteristics for the 0- to 300-mm depth were 230 g kg^{-1} sand, 380 g kg^{-1} silt, and 390 g kg^{-1} clay; 1:1 soil:water pH of 6.5; total C content of 29.5 g kg^{-1}, and total N content of 2.4 g kg^{-1}. The location has a humid continental climate (USDA, 1981) with mean precipitation of 848 mm yr^{-1} and a mean annual temperature of 9.1 C. The research site was cropped in a corn/soybean rotation using ridge tillage without manure application since 1983.

Our cooperator overseeded a mixture of oats (*Avena sativa* L.) and hairy vetch into corn on 7 September 1987, at rates of 22 and 34 kg ha^{-1}, respectively. H allowed the cover crop to grow in a undisturbed strip that was 7.3 m (8 rows wide until it was incorporated during th ridge tillage planting operation in 198 An adjacent eight-row strip was diske after corn harvest in mid-October t smooth the ridges and to incorporat corn stover plus the newly emerge cover crops. Compared to corn stove biomass contributions from the cove crops in autumn were negligible.

The disked strip was left bare throug the winter (except for snow cover). was disked again in late April and earl May, 1988, prior to planting soybea with a Buffalo Ridge-Till planter at seeding rate of about 436,000 seed ha in rows spaced 0.91 m apart. Soil test and K levels were adequate (data no presented), so no fertilizer was applied In the non-disked strip, the planting op eration buried most of the hairy vetc cover crop and 1987 corn residue so tha after planting, surface soil condition were similar with and without the cove crop treatment. The surface 20 mm wa tilled with a rotary hoe approximately and 14 days after planting to contro early season weeds. New ridges were es tablished in both disked and non-diske strips by cultivating twice during Jun with a Buffalo Ridge-Till cultivator.

We established four plots, 9.1 m i length or 66 m^2 in area, within each stri for soil and plant sampling. We mea sured the amount of corn stover re maining from 1987 and the amount c vetch cover crop by collecting two 1 m samples prior to planting. To measur soybean growth, we collected two sam ples, 1 m long, from rows within eac plot on 20 June, 22 July, 4 August, 3 August, and 28 September 1988. Thi corresponded to 33, 65, 78, 105, and 13 days after planting (DAP). We deter mined total dry weight and counted th number of plants before grinding sam ples to pass a 0.5 mm screen. We used Carlo Erba NCS-1500 elemental ana lyzer (Schepers et al., 1989) to measur total C and N concentrations.

Our cooperator seeded a mixture c oats, rye, and hairy vetch on 17 Septem ber 1988 at rates of 22, 17, and 34 k ha^{-1}, respectively. These seeding rate were based on previous on-farm trial

(R. L. Thompson, personal communication, 1990). The disked strip was tilled in October and again in late April and early May, 1989, prior to planting corn. On 5 May, we collected two 1 m^2 samples from each ridge tillage plot and measured the amount of corn stover (from 1987), soybean residue (from 1988), vetch, and rye in each sample. The residues were separated, dried, weighed, ground, and analyzed using dry combustion techniques. Corn was planted with a Buffalo planter on 6 May 1989 at a seeding rate of 66,200 seed ha^{-1} and with a band application of 83 kg ha^{-1} K.

Four 66-m^2 plots were reestablished in each strip. Within each eight-row strip, four corn rows (16 m^2) were fertilized with ^{15}N depleted NH_4NO_3 (ammonium nitrate) fertilizer at a rate of 67 kg N ha^{-1} on 29 May. The four adjacent rows were fertilized with normal abundance NH_4NO_3. Fertilizer materials were dissolved in water, broadcast uniformly with 28 L of water using a sprinkling can, and incorporated by applying 4.6 mm (76 L/plot) of water. Accumulated growing degree units (GDUs) were calculated with Eq. [1] (Shaw, 1977), using air temperature data from the Iowa State University Agronomy and Agricultural Engineering farm, which is located 4 mi south of the research site.

$$GDU = [(Tmin' + Tmax')/2] - 10\ C \quad [1]$$

where Tmin' is minimum daily temperature or 10 C, whichever is larger.

Tmax' is maximum daily temperature or 30 C, whichever is smaller.

We collected soil samples seven times from soybean plots in 1988. We used a soil probe 25 mm in diameter to sample from within and between rows to a depth of 30 cm before planting (10 May) and at 2 to 4 week intervals until after harvest (17 October). In 1989, we collected soil samples five times (24 April, 15 May, 20 June, 25 July, and 3 October) from the ^{15}N plots. Data from both positions were averaged for this report.

We collected plant samples from the non-isotope plots on 21 June, 7 July, 25 July, 7 August, 22 August, and 3 October, and from ^{15}N-depleted plots on 21 June, 25 July, and 3 October 1989. For each sampling date, four to six plants were randomly selected from within the 16 m^2 fertilized areas. Plants were dried, weighed, ground to pass a 0.5 mm screen, and analyzed using dry combustion techniques. To quantify fertilizer N recovery and efficiency of use, the atom percentage ^{15}N was determined as described by Schepers et al. (1989). Percent N derived from fertilizer (%NDFF) and N recovery efficiency (NRE) were calculated using Eq. [2] and Eq. [3], respectively, which were adapted from Pomares-Garcia and Pratt (1978).

$$\%\ NDFF = [(C - B)/D] * 100 \quad Eq.\ [2]$$

where C = natural abundance of ^{15}N, which is 0.3663%

B = atom percent ^{15}N in plant tissue

D = excess atom percent ^{15}N in the applied fertilizer which was (0.3663 - 0.01) because ^{15}N-depleted fertilizer was used.

$$NRE = [(\%NDFF/100) * NF]/R \quad Eq.\ [3]$$

where NF = total N uptake by the plant or plant fraction

R = the rate of ^{15}N fertilizer applied (67 kg N ha^{-1})

We statistically compared plant growth, N concentration, and yield measurements from the four plots within each strip using PROC TTEST (SAS Institute, 1985).

Growth and N concentrations for the ^{15}N-depleted and nondepleted fertilizer treatments were similar. Therefore, to determine accumulation rates, we created a data set with six measurements of aerial biomass and N accumulation for each tillage by cover crop treatment. We calculated mean values for each sampling date and fit them mathematically using compound cubic polynomials. The equations were generated with a clamped cubic spline interpolant program (Burden et al., 1981) with endpoint (planting and physiologic maturity) derivatives set to zero. This program forced the fitted curve and its first and second derivatives to be continuous at each data point. We differentiated the interpolant polynomials to determine rates of dry matter and N accumulation. Aerial biomass and N accumulation curves were plotted using accumulated GDUs as a time scale. We compiled a similar data set with five observations for the 1988 soybean crop but plotted those data as a function of days after planting (DAP) because indeterminate soybean growth and development has not been described as a function of GDUs.

Results and discussion

On-site rainfall for 1988 and 1989 was 588 and 576 mm, respectively. This amount was approximately 30 percent below the 23-year county average (USDA, 1981). The weather patterns were similar, but March temperature in 1988 averaged 4.6 C compared to 1.6 C in 1989 (Figure 1). This temperature difference may have caused hairy vetch to grow more rapidly in 1988, thus increasing biomass and N accumulation (Table 1), since April temperature averaged 10.2 C in 1988 and 10.6 C in 1989.

The amount of crop residue and cover crop growing on the nondisked ridges prior to planting the soybean and corn crops is presented in Table 1. Similar amounts of corn stover and soybean residue were presumably incorporated in the disked strips, but the amount of biomass produced by cover crops prior to autumn disking was negligible. In contrast to the

Table 1. Cover crop and surface residue characteristics prior to planting soybean in 1988 or corn in 1989.

Plant material	Amount (kg ha^{-1})	C:N	N concentration (g kg^{-1})	N contribution (kg ha^{-1})
			1988	
1987 Corn stover	6057	47:1	8.4	51
Hairy vetch	874	8:1	45.7	40
			1989	
1987 Corn stover	520	37:1	8.3	4
1988 Soybean residue	2409	49:1	8.2	20
Winter rye	878	12:1	36.3	32
Hairy vetch	483	10:1	38.0	18

Table 2. Aerial soybean biomass and N accumulation as influenced by a cover crop treatment in 1988. Mean and (standard deviation)

Cover crop management	Biomass (kg ha^{-1})	Mean and (standard deviation) (kg ha^{-1})
	June 20 (33 DAP)	
Disked, without cover	626 (104)	15.6 (3.1)
Ridge-Till, with cover	516 (71)	12.3 (2.4)
Significance level	0.13	0.15
	July 22 (65 DAP)	
Disked, without cover	2,938 (704)	95.6 (27.5)
Ridge-Till, with cover	2,342 (385)	72.1 (16.7)
Significance level	0.19	0.19
	August 4 (78 DAP)	
Disked, without cover	5,398 (519)	114.5 (21.4)
Ridge-Till, with cover	5.086 (789)	108.6 (19.0)
Significance level	0.37	0.57
	August 31 (105 DAP)	
Disked, without cover	6,760 (2015)	89.2 (22.8)
Ridge-Till, with cover	6,857 (892)	90.7 (19.9)
Significance level	0.90	0.89
	September 28 (133 DAP)	
Disked, without cover	5,863 (1141)	201.0 (37.0)
Ridge-Till, with cover	4,993 (923)	169.5 (14.1)

Table 3. Aerial corn biomass and N accumulation as influenced by a cover crop treatment in 1989.

Cover crop management	Biomass (kg ha^{-1})	Mean and (standard deviation) (kg ha^{-1})
	June 21 (46 DAP)	
Disked, without cover	700 (73)	24.6 (2.7)
Ridge-Till, with cover	456 (70)	14.0 (2.8)
Significance level (2-sided t-test)	0.003	0.002
	July 7 (62 DAP)	
Disked, without cover	3,960 (243)	67.2 (3.9)
Ridge-Till, with cover	3,517 (501)	66.9 (10.8)
Significance level	0.16	0.96
	July 25 (80 DAP)	
Disked, without cover	5,443 (608)	80.4 (11.2)
Ridge-Till, with cover	4,698 (346)	63.1 (9.7)
Significance level	0.08	0.06
	August 7 (93 DAP)	
Disked, without cover	11,014 (670)	94.4 (25.0)
Ridge-Till, with cover	11,019 (1051)	91.6 (18.8)
Significance level	0.99	0.86
	August 22 (108 DAP)	
Disked, without cover	16,036 (1540)	113.1 (22.5)
Ridge-Till, with cover	14,646 (1274)	102.5 (8.9)
Significance level	0.21	0.42
	October 3 (150 DAP)	
Disked, without cover	16,382 (893)	149.4 (4.6)
Ridge-Till, with cover	14,013 (498)	123.4 (9.7)
Significance level	0.004	0.003

amount of biomass produced and th amount of N that a vetch cover crop ca contribute to subsequent grain crops i more southern locations (Frye et al 1988; Smith et al., 1987), the amoun produced at our research site was rela tively small. This reflects the muc shorter growing season in the northern Corn Belt and is one reason why farmer are reluctant to invest money in seed fo materials such as hairy vetch.

The weather data (Figure 1) show tha winter precipitation can be quite low. I spring rainfall is low, cover crops ca deplete available soil water and creat problems for emergence and stand estab lishment for the primary grain cro (Campbell et al., 1984; Karlen, 1989) However, if excessive or periodically in tense spring rainfall occurs, soil aeratio can be reduced, especially in wheel-trac areas, and soil nitrogen can be los through denitrification (Doran et al 1989).

Aerial biomass and N accumulatio by both soybean and corn were generall slower where crop residues and cove crops had been incorporated at plantin (ridge tillage) than where they were in corporated by autumn disking (Tables 2 and 3). The difference in total N accu mulation for soybean was statistically significant only at maturity. Means fo the corn crop were significantly differen for aerial biomass and N accumulatio on 21 June and 3 October (Table 3) Grain yields after a cover crop wer grown were slightly lower for soybea (2640 ± 268 vs 2918 ± 472 kg ha^{-1}) an corn (8916 ± 412 vs 9952 ± 207 k ha^{-1}) than where crop residues had bee incorporated by autumn disking. W suggest that this occurred because earl season growth and development wer slower for plants growing after a cove crop so that potential grain yields wer lower.

Slightly slower plant growth, develop ment, and yield with conservation tillag in the upper Corn Belt are not unusua (Karlen, 1990) because soils are ofte cool and wet, but ridge tillage often mini mizes those effects. Measurements be fore planting at this site showed that so temperatures in the surface 0 to 75 m were 4 to 6 C cooler in undisturbed ridg tillage strip than in the disked strip, bu

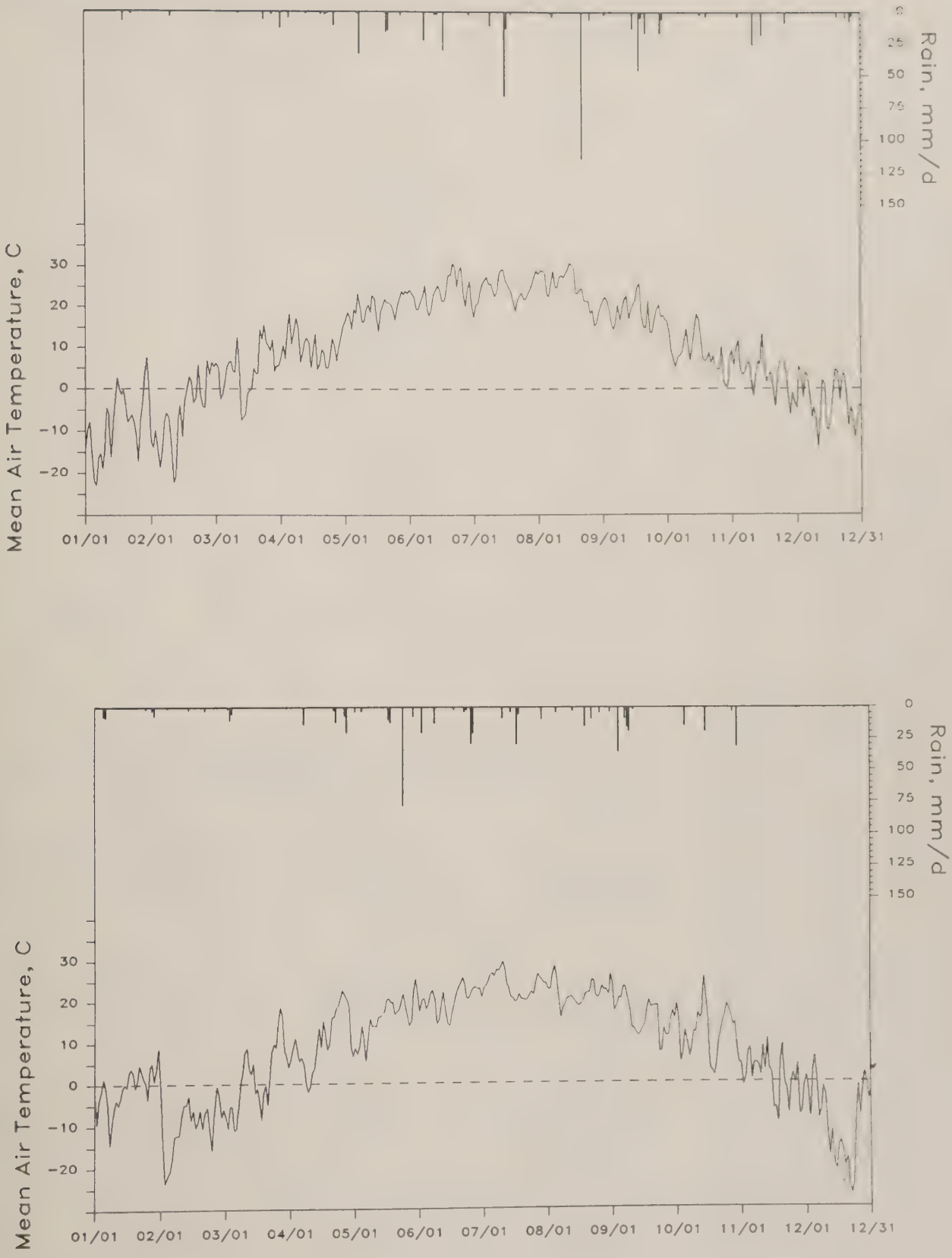


Figure 1. Mean air temperature and rainfall in 1988 (top) and 1989 (bottom).

differences in soil temperature after planting were negligible (data not shown). This change probably occurred because the Buffalo Ridge-Till planter moved most of the soil, crop residue and cover crop from the ridges during planting and thus created similar surface conditions for both the cover crop and non-cover crop treatments. The θ_v water content was significantly higher with ridge tillage management before or near planting. Later in the growing season, soil water content for the two management systems was similar (Table 4). Soil NO_3-N in the top 30 cm was generally lower for cover crops with ridge tillage than where they had been killed by autumn disking (Table 4). Other research data suggests that greater denitrification or lower net N mineralization occurred because of cooler, wetter, and more compact soil conditions and because of greater surface residue accumulation with ridge tillage, especially in the areas between the rows (Doran et al., 1989).

The %NDFF and NRE for the 1989 corn crop are presented in Table 5. Slightly more fertilizer N was recovered with ridge tillage where cover crops had been grown, presumably because residual soil N was lower (Table 4). However, yields were also slightly lower for the ridge tillage treatment, so NRE values were not different (Table 5). Fertilizer recovery efficiency in the grain for both tillage treatments was slightly less than 30 percent even though the fertilization rate was relatively low. Total aerial accumulation of the ^{15}N fertilizer averaged 36.1 percent with a cover crop and 38.7 percent without. The lower soil NO_3-N concentration suggests that fertilizer N may be needed to overcome lower available soil N levels for ridge tillage with cover crops. Perhaps the NRE could be improved with band placement of the fertilizer rather than broadcast applications.

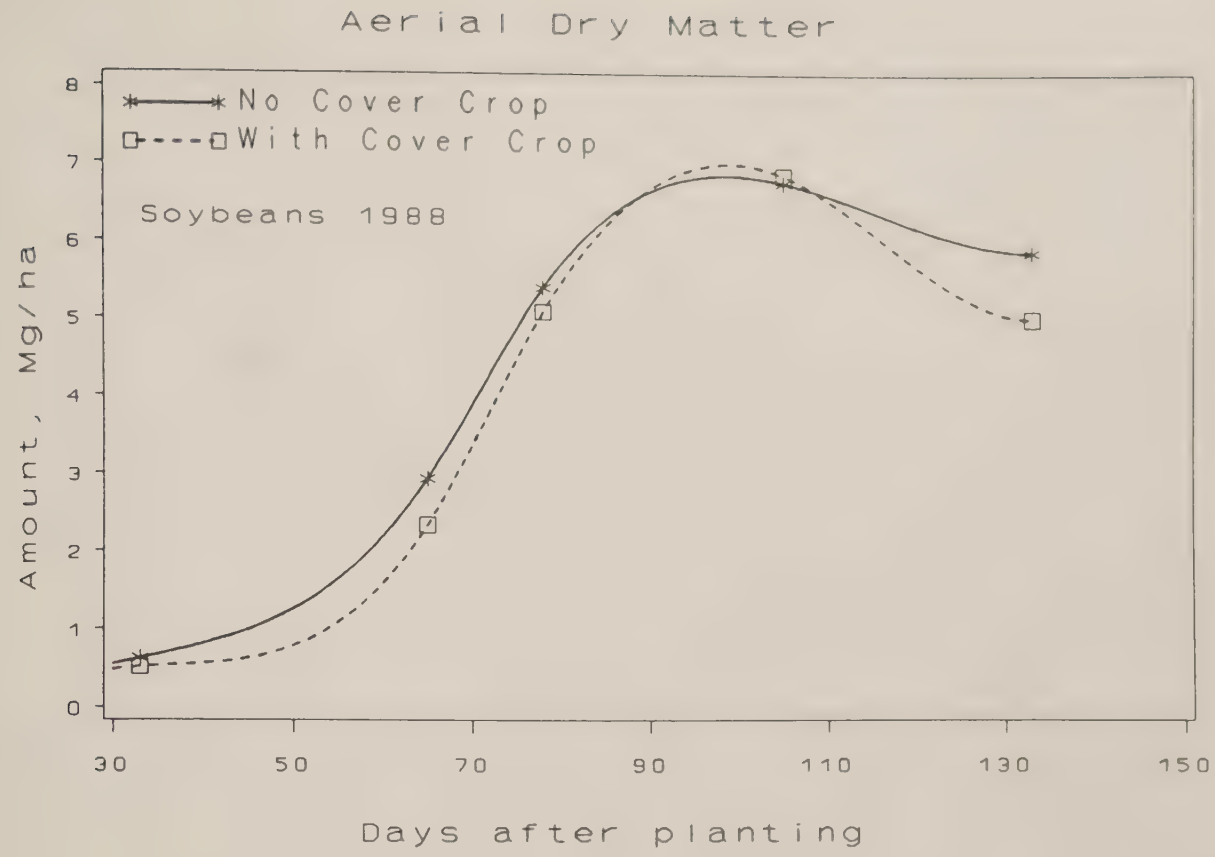
Graphs of aerial dry matter (Figure 2) and N accumulation (Figure 3) for soybean show that the primary difference between treatments was that both growth and N accumulation occurred earlier and at a higher rate in the absence of cover crops. The more rapid early season growth probably helped establish stronger plants with greater yield poten-

Table 4. Cover crop effects on soil N and volumetric water content in the top 30 cm in 1988 and 1989.

Cover crop management	Date	No_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	θ_vw cont
	Soybean, 1988			
Ridge, with cover	May 10	46.9		0.37
	May 24	48.8		0.36
	June 13	59.4		0.32
	June 27	62.9		0.29
	August 3	43.3		0.25
	September 14	28.2		0.28
	October 17	21.4		0.36
Disked, w/o cover	May 10	58.3		0.36
	May 24	62.1		0.37
	June 13	64.9		0.33
	June 27	70.8		0.29
	August 3	38.3		0.23
	September 14	30.7		0.28
	October 17	25.4		0.36
	Corn, 1989			
Ridge, with cover	April 24	26.9	8.8	0.36
	May 15	25.0	9.4	0.34
	June 20	52.8	7.8	0.30
	July 25	18.7	6.6	0.27
	October 3	17.4	6.8	0.33
Disked, w/o cover	April 24	49.6	9.9	0.35
	May 15	66.9	6.8	0.33
	June 20	77.0	8.5	0.28
	July 25	21.2	5.5	0.26
	October 3	15.8	6.3	0.32

Table 5. Nitrogen percentage derived from fertilizer (%NDFF) and N recovery efficiency (NRE) for cor grown with and without a cover crop in 1989. Mean and (standard deviation).

Cover crop management	Plant part	%NDFF	NRE
		June 21	
Ridge, with cover	Whole plant	30.4 (4.1)	0.065 (0.020
Disked, w/o cover	Whole plant	17.3 (2.0)	0.063 (0.006
Significance level (2-sided t-test)		0.001	0.06
		July 25	
Ridge, with cover	Whole plant	28.5 (0.9)	0.269 (0.046
Disked, w/o cover	Whole plant	18.6 (2.0)	0.222 (0.029
Significance level		0.001	0.14
		October 3	
Ridge, with cover	Stover	21.0 (1.4)	0.081 (0.02
Disked, w/o cover	Stover	17.0 (0.6)	0.092 (0.01
Significance level		0.002	0.40
		October 3	
Ridge, with cover	Cob	19.8 (1.4)	0.015 (0.00
Disked, w/o cover	Cob	17.8 (2.1)	0.012 (0.00
Significance level		0.17	0.55
		October 3	
Ridge, with cover	Grain	19.0 (1.0)	0.265 (0.02
Disked, w/o cover	Grain	17.4 (1.9)	0.283 (0.03
Significance level		0.18	0.42



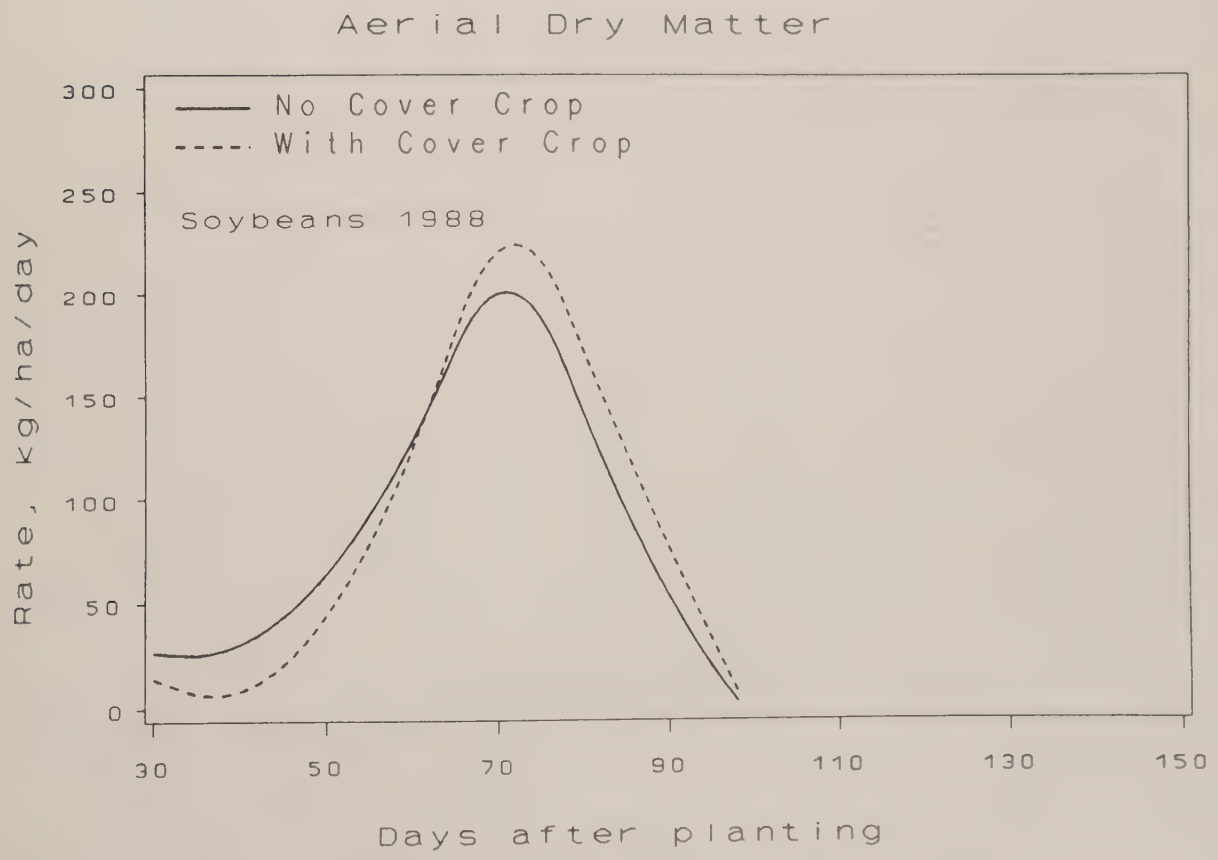
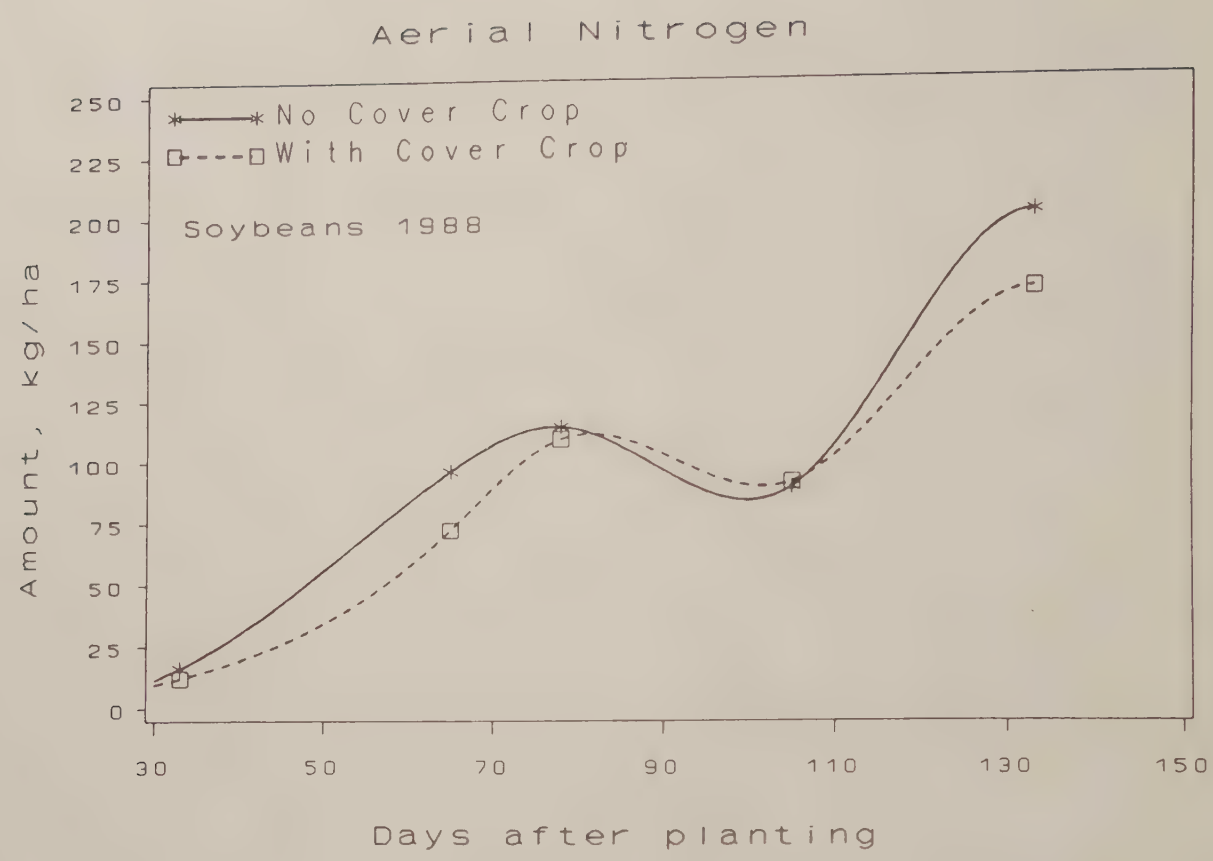


Figure 2. Amount (top) and rate (bottom) of aerial dry matter accumulation by soybean grown with and without a cover crop.



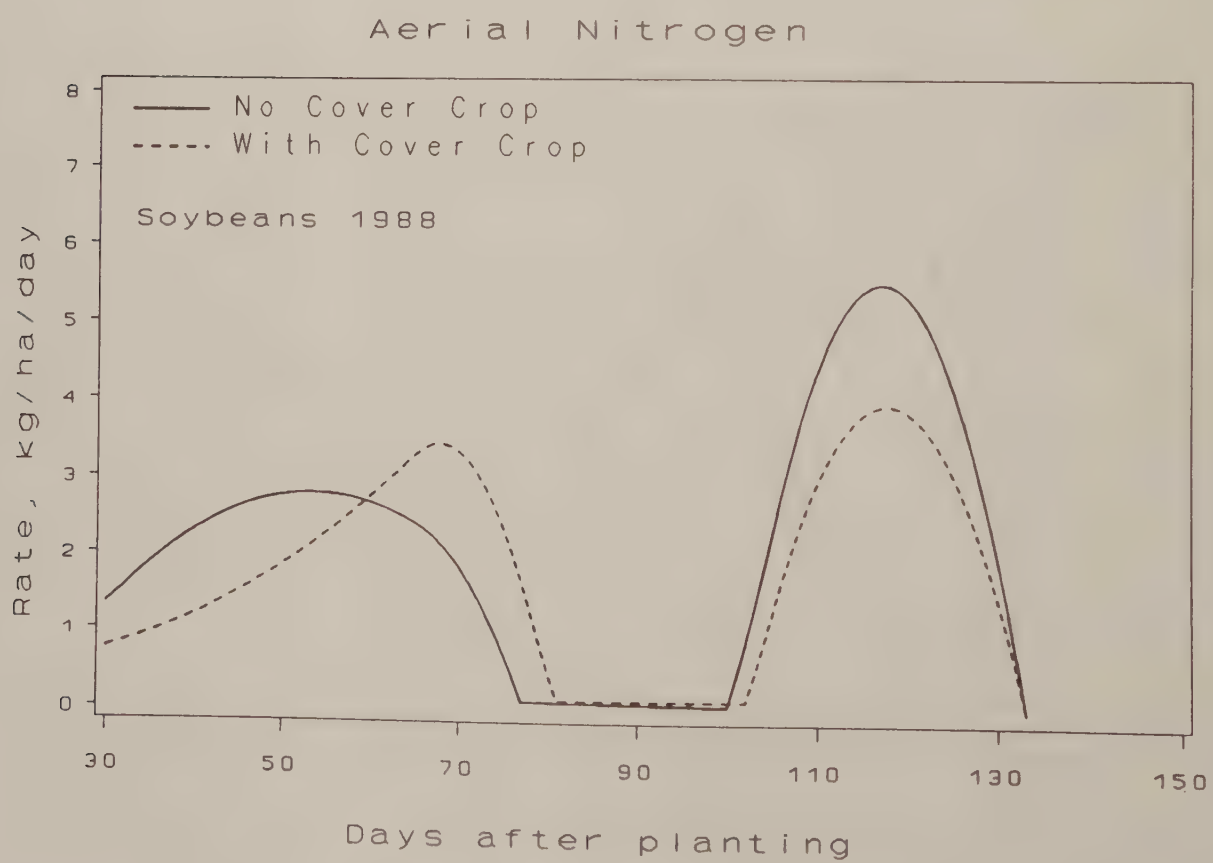


Figure 3. Amount (top) and rate (bottom) of aerial N accumulation by soybean grown with and without a cover crop.

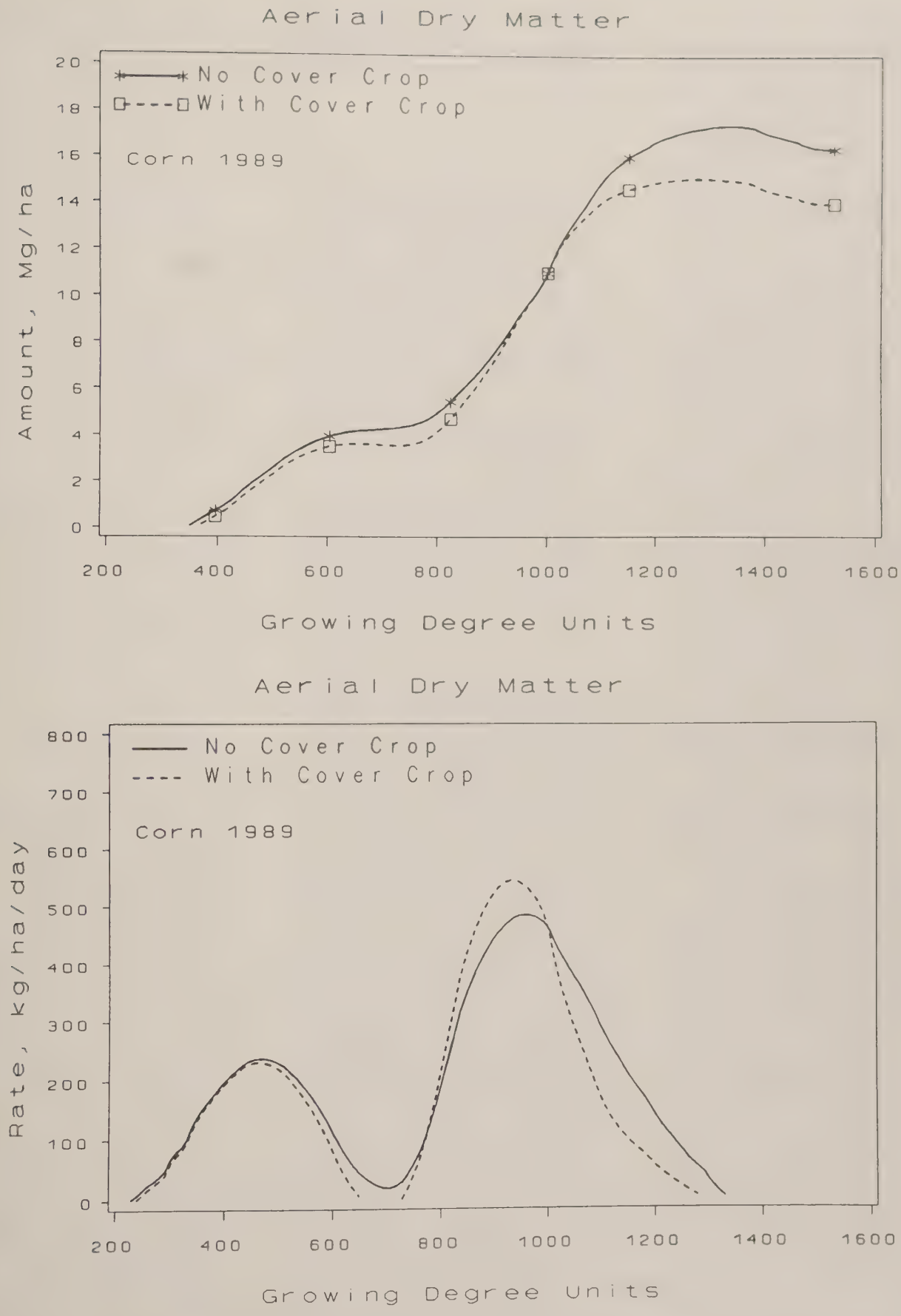


Figure 4. Amount (top) and rate (bottom) of aerial dry matter accumulated by corn grown with and without a cover crop.

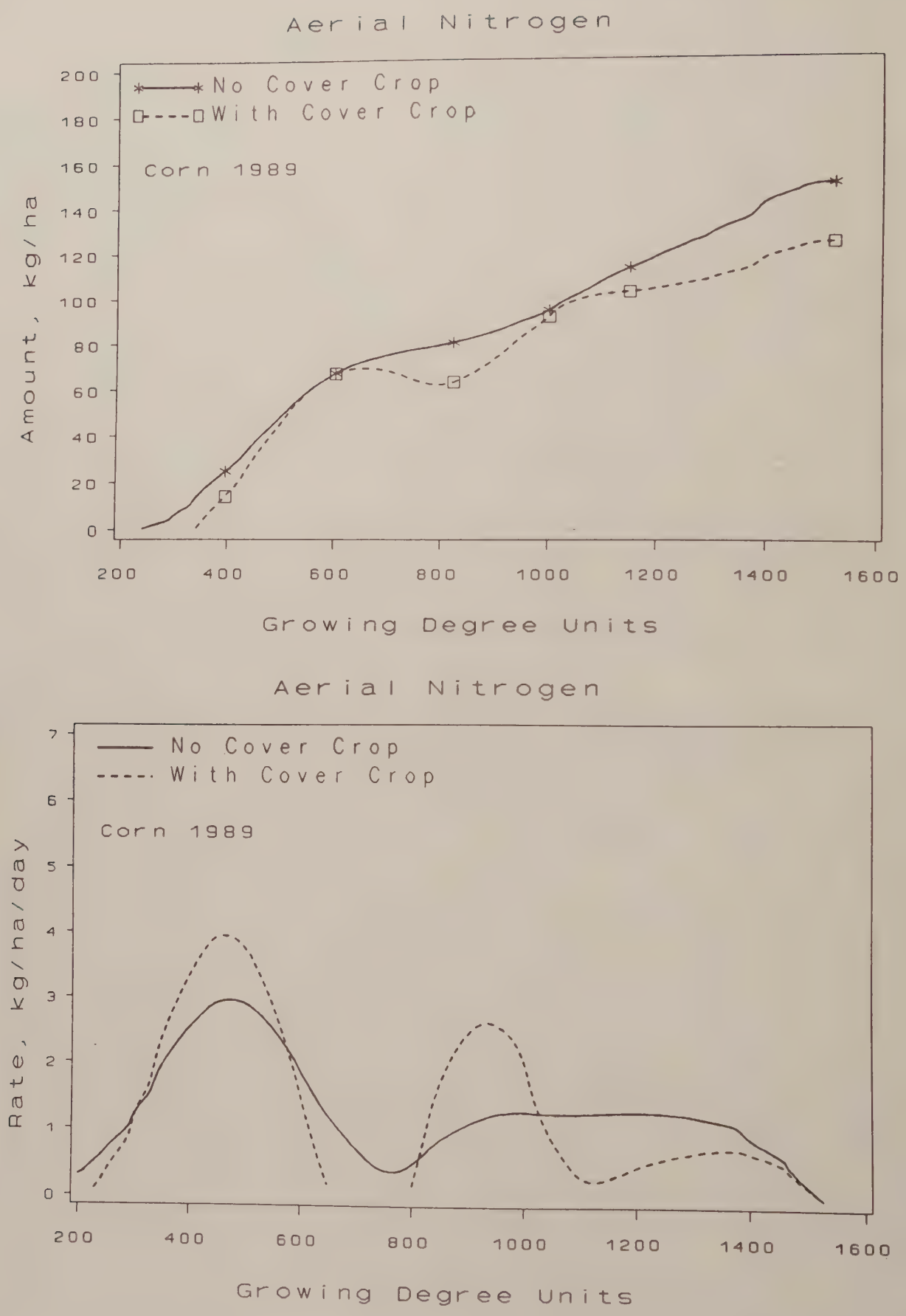


Figure 5. Amount (top) and rate (bottom) of aerial N accumulation by corn grown with and without a cover crop.

tial. The amount and rates of accumulation of aerial dry matter and N for both treatments were similar to those described for determinate soybean cultivars receiving recommended tillage and fertilizer management (Karlen and Sadler, 1989).

For corn in 1989, differences in the amount and rate of aerial dry matter accumulation (Figure 4) for the two treatments were small. Aerial N accumulation (Figure 5) was greater where crop residues and emerging cover crops were incorporated by autumn disking. Although the daily rate of N accumulation was lower in plots that had been disked, grain yield and total N accumulation were greater because N was accumulated for a longer period during grain fill. As with other corn data sets that have been analyzed using the splining technique (Karlen et al., 1987a, 1987b, 1988), distinct periods of vegetative and reproductive growth and N accumulation were evident for both treatments. This indicated that there were no unusual plant growth and development patterns with or without cover crops.

Summary and conclusions

We evaluated soybean and corn growth, N accumulation, and yield in central Iowa to determine the effects of winter cover crops in an on-farm research study. The cover crop added approximately 875 to 1260 kg/ha of biomass. However, decomposition of the cover crops apparently reduced soil NO_3-N levels in the top 30 cm of the soil profile. This resulted in slightly lower amounts and rates of aerial biomass accumulation for corn. Calculations of NRE for broadcast ^{15}N-depleted fertilizer accounted for 36.1 and 38.7 percent of the N in the corn plants. Postemergence broadcast N application apparently did not overcome the early season stress. This suggests the need for studies evaluating row or band placement of fertilizer to determine if advantages of cover crops, such as erosion control, can be obtained without sacrificing yield of the primary grain crops.

Acknowledgment. We thank Mr. and Mrs. Richard Thompson for providing an on-farm research site, collecting on-site rainfall data, and conducting all the field operations needed for this cooperative research project to be successful.

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INSTITUTE NEWS

Dr. Richard J. Sauer is Named to IAA Board

At its regular mid-year meeting on September 7 in Ames, Iowa, IAA's Board of Directors elected Dr. Richard J. Sauer to a three-year term on the Board. Dr. Sauer is President and Chief Executive Officer of the National 4-H Council in Bethesda, Maryland. Prior to assuming his present position in 1989, Dr. Sauer spent 8 1/2 years at the University of Minnesota as Director of the Agricultural Experiment Station, with the last 5 1/2 years as Vice President for Agriculture, Forestry, and Home Economics. Trained in entomology, he also has served in several other research and administrative posts, including a brief tenure as Interim President of the University of Minnesota.

West Virginia University Economist is IAA Visiting Scholar

Gerard D'Souza, an Agricultural Economist at West Virginia University in Morgantown, West Virginia, is spending three months at the IAA studying possible ways to overcome limitations of economics research techniques for analyzing alternative agriculture. At West Virginia University since 1984, D'Souza has taught and conducted research on the economics of agricultural production, farm management, and finance. With a growing interest in alternative agriculture, he has been involved in studies of biological brush control, extended grazing, recycling, and farmers' adoption of alternative practices. D'Souza has a Ph.D. in agricultural economics from Mississippi State University.

Youngberg Receives Award

Dr. Garth Youngberg, Executive Director of the IAA, has received an Alumni Achievement Award from the College of Liberal Arts and Sciences Alumni Association at the University of Illinois. The awards recognize an alumnus or alumna who, by outstanding achievement, has demonstrated the values derived from a liberal arts and sciences education. Youngberg earned his Ph.D. in political science from the University of Illinois in 1971, with an emphasis in agricultural policy and administration. As Executive Director of the IAA, which he helped found in 1983, Youngberg "has been consistently in the forefront of issues related to competitiveness, environmental considerations, food safety, and policy," according to the award. In nominating Youngberg for the award, Professor Emeritus of Political Science Phillip Monypenny wrote, "None has made a personal contribution so substantial to a movement attempting solutions to a problem as knotty intellectually, scientifically, as well as politically, as creating an agricultural system which avoids practices increasingly destructive to the environment while rewarding those who operate it, and whose livelihoo depends on it, with an appropriate an stable level of return."

Maureen Hinkle Addresses Budapest Conference

Maureen Hinkle, Director of Ag ricultural Policy, National Audubo Society, and a member of IAA's Boar of Directors, was the non governmental organization representa tive invited to address a workshop hel in Budapest, September 16-20, 199 The workshop was one of three involv ing scientists from the U.S. and Easter Europe to develop a major proposal t USAID for three-year funding for agr culture projects in Hungary, Romania Poland, Yugoslavia, and Czechoslova kia. The Budapest workshop dealt wit maximizing biological control in inte grated pest management systems fo potatoes, wheat, and apples. IPM ha developed a research base and an exten sion outreach to many farmers. By cen tering IPM projects on biological con trol, chemical use should b dramatically reduced, and any us must be compatible with biologica controls. The result should be reduce costs to farmers and improvement fo human health and the environmen The second workshop will addres ground water, and the third soi erosion.

For information, contact Maureen Hinkle at (202) 547-9009, ext. 3228.

An economic assessment of maintaining high phosphorus and potassium soil test levels

Craig Chase, Michael Duffy, John Webb, and Regis Voss

Abstract. *Phosphorus (P) and potassium (K) fertilization costs, yields, and economic returns associated with various P and K fertilization levels were evaluated on corn and soybeans in rotation in northeastern Iowa from 1979 to 1989. The treatments were 0, 20, and 40 lb P/acre and 0, 60, and 120 lb K/acre, in all nine combinations, plus the high rate (40+120) applied on alternate years. (The latter treatment applied, respectively, in odd or even years was averaged into one treatment.) The initial soil test levels averaged 57 pounds of P and 355 pounds of K. The P-K treatments did not significantly explain the variation in corn or soybean yields. Net returns were found directly related to the cost of the treatment, so that the control treatment (0+0) achieved the highest returns. The cost of using the 20+60 treatment to maintain soil test levels in the high to very high range was $24/acre per year. Annual application of 40+120 cost $45/acre. A sufficiency approach to applying P and K could drastically reduce fertilizer costs for high-testing soils. Further research is needed to determine if recommendations from this approach can be lowered in some cases. Extension workers must continue to develop ways to aid farmers in realizing the usefulness of soil testing. Farmers must carefully evaluate their fertilization needs in conjunction with soil test results. Together, a more sustainable approach to P and K fertilization for corn and soybeans may be attained.*

Key words: phosphorus, potassium, application levels, agricultural profitability, soil test levels

Introduction

Phosphorus (P) and potassium (K) are essential elements for corn and soybean growth. Deficiencies in these elements will result in lower crop yields, whereas their overapplication will lower economic returns (Tisdale et al., 1985). Thus, the key to agronomically and economically efficient fertilizer application is to compare soil nutrient levels to the fertility needs of the crops grown. Soil testing is a management tool that can be used to evaluate these needs and to determine the application rate needed to supplement existing soil nutrients. Moreover, the application rate should be suited to historical yields or the potential productivity of the soil (Miller, 1986).

Long-term impact of annual nitrogen (N) and P applications on corn were analyzed by Hooker et al. (1983) in two experiments in western and west-central Kansas, using P applications of 0, 20, and 40 kg/ha. They found a significant yield response when P rate increased from 0 to 20 kg/ha. However, yields did not increase as rates increased from 20 to 40.

Olson et al. (1982) analyzed three approaches to soil testing. Two of these approaches were maintenance and sufficiency. The third, the cation-saturation ratio, defines a soil as an ideal type based on a predetermined distribution of exchangeable cations. Because the proportions of exchangeable cations depend on clay content, the researchers concluded that the cation-saturation ratio was not a major consideration in soil test interpretations. Thus the third approach will not be discussed here.

The maintenance approach recommends replacing nutrients removed by the crop, regardless of soil test level. The sufficiency concept is similar to the maintenance approach, except that no fertilizer application is recommended when test results are above a predetermined soil test level. Iowa State University subscribes to this approach, as do most universities. Olson et al. (1982) tested the approaches on continuous corn in four Nebraska locations over the period 1973-1980. They concluded that maintenance recommendations are not economical when soil nutrients are already at levels needed for optimal yields. The sufficiency method was more economical because of lower recommended application rates under higher soil test conditions.

Tillage and fertilizer management on soybeans were analyzed by Hairston et al. (1990) at three Mississippi locations (two from 1983 to 1985 and one from 1984 to 1985). The combinations of P and K analyzed were 0+0, 13+37, and 40+112 pounds per acre. The 0+0 served as a control, whereas the 13+37 and 40+112 were considered the maintenance and three-times-the-maintenance yearly application levels. Initial soil test levels at the three experimental sites were very low to low in P and very low to medium in K. Corn yield re-

The data analysis for this paper was supported in part by the Iowa Department of Natural Resources, through the Big Spring Basin Demonstration Project. Funds were provided through the Iowa Groundwater Protection Act and Petroleum Violation Escrow Accounts and other sponsoring agencies: U.S. Department of Agriculture Soil Conservation Service and the U.S. Environmental Protection Agency, Region VII, Kansas City. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the view of the U.S. Department of Energy.

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sponses to P and K were less than the authors anticipated, and economic returns decreased as application rates increased. Rainfall distribution and soil depth influenced yields more than the tillage and fertility treatments.

The initial P and K test levels in the study reported here were 57 pounds and 355 lb, respectively. In Iowa, these levels are classified as high and very high and allowed for analyzing the long-term impacts of varying fertilization rates. The questions asked were: how long does it take for initial levels to drop to where crops would respond to annual P and K applications, and what are the costs and returns to annual applications? The study examined costs, yields, and economic returns associated with various P and K fertilization levels, including the effect of overapplication on returns.

Materials and methods

The primary data for this analysis comes from an Iowa State University P and K fertilization study conducted at the Northeast Research Center, southwest of Nashua, Iowa, in Floyd County. This paper reports results from the experiment for the period 1979-1989.

Study design

Ten treatment combinations of P and K were evaluated. Rates were 0, 20, and 40 lb P/acre and 0, 60, and 120 lb K/acre. Two treatments of the high rate (40+120) applied in either odd or even numbered years were averaged into one treatment for this analysis. Each treatment was replicated three times over a corn-soybean rotation. The corn and soybean crops were grown on alternating field areas. Soil samples were taken in the fall after the removal of the soybean crop. The experiment was located on predominantly Kenyon (fine-loamy, mixed, mesic Typic Hapludolls) and Readlyn (fine-loamy, mixed, mesic Aquic Hapludolls) soils. Both soils were slightly sloping, with a slope of 1 to 3 percent.

Field operations

The P and K treatments were broadcast in the fall and incorporated with a chisel plow. Nitrogen fertilizer (NH_3) was applied to the corn in the spring. Nitrogen rates varied by year between 150 and 180 lb N/acre but were constant across treatments. Tillage, pesticide applications, and hybrids were also identical among treatments. The control plot, however, did not incur the spreading cost for fall fertilization.

Application levels

Initial soil test levels averaged 57 lb (high) of P and 355 lb (very high) of K. The corn and soybean crops would remove 24 and 16 lb of P and 36 and 56 lb of K, respectively, given average yields of 145 and 45 bu/acre. A 20+46 rate on average should suffice to meet nutrient requirements. Given the combinations of P and K in the experiment, however, the 20+60 treatment will be considered the maintenance rate. The 20+60 rate maintained both P and K in the high to very high range throughout the period (Table 1).

Given the initial soil test levels, Iowa State's sufficiency recommendations would be to fertilize at a maintenance level for P, discontinue applications of K (Voss and Agronomy Dept. Staff, 1982), and retest in two to four years. After two years, the 1981 soil test results (where application rate had been 20+0) indicated that P and K were 66 pounds (very high) and 250 pounds (high), respectively. Such levels indicate that P fertilization should discontinue and that K should be fertilized at maintenance rates (0+60). To evaluate the sufficiency proach, it would be necessary to c tinue changing fertilizer levels based test results through 1989. The exp ment, however, was intended to de mine the effects of different constant tilization rates on soil test levels a therefore does not allow for a direct an ysis of the sufficiency approach.

All treatments with annual P rates 20 pounds or more maintained P in very high range, whereas all treatme with annual K rates of 60 pounds more (except 20+60) maintained K the very high range (Table 1).

Results

Fertilization costs

Actual expenses for cultural practi were not kept in the experiment. The fore, expense data were estimated us production costs from Duffy (1990 a previous years). This publication is u dated and revised yearly. Identical ti age practices allowed us to focus on t varying treatment costs only. The pric for P and K varied annually, accordi to Duffy (1990 and previous years). and K fertilization costs are presented Table 2. The cost of spreading and int est on operating costs was included reflect more accurately the costs of va ous treatments. The treatment co range from $0 per acre for the cont plot to $45 per acre for the 40+120 a nual treatment. The 40+120 treatme in alternating years and the 20+60 tre

Table. 1 1989 Soil test levels by P and K treatment

P-K treatment lb/acre	1989 Soil Test Levels[1]	
	P	K
0+0	28 L	137
0+60	33 M	339 V
0+120	32 M	565 V
20+0	79 VH	159
20+60	66 VH	271
20+120	73 VH	533 V
40+0	162 VH	182
40+60	139 VH	313 V
40+120	138 VH	569 V
40+120 (alt. years)	68 VH	272

[1] L=low (P 16-30, K 71-135), M=medium (P 31-40, K 136-200), H=high (P 41-60, K 201-300), VH=v high (P 61 or more, K 301 or more). See Voss et al. (1982) for additional information regarding soil t level classification.

Table. 2 Average phosphorus and potassium costs per acre by treatment for a corn-soybean rotation, 1979-1989

P-K treatment lb/acre	Fertilizer cost	Spreading cost[1] $/acre	Total Costs[2]
0+0	$ 0	$ 0	$ 0
0+60	9	3	13
0+120	18	3	23
20+0	10	3	14
20+60	19	3	24
20+120	28	3	33
40+0	20	3	27
40+60	30	3	35
40+120	39	3	45
40+120 (alt. years)	19	1	22

[1] Spreading costs include both fixed and variable costs.
[2] Includes a 7 percent interest charge on the fertilizer and spreading costs.

Table. 3 Yields by crop and treatment, 1979-1989[1]

P-K treatment lb/acre	Yield (bu/acre) Corn	Soybean
0+0	140[1]	41[1]
0+60	142	41
0+120	140	41
20+0	139	41
20+60	141	41
20+120	143	42
40+0	141	41
40+60	142	42
40+120	143	42
40+120 (alt. years)	142	41

[1] Variation in yields were not significantly explained by the P-K treatments in the ANOVA analysis.

Table. 4 Average annual returns to land and management, by crop, treatment, and rotation, 1979-1989[1]

P-K treatment lb/acre	Annual returns ($/acre) Corn	Soybean	Rotation
0+0	$ 149 a	$ 136 a	$ 143 a
0+60	139 a,b	121 b	130 b
0+120	125 b,c,d	113 b,c	119 c,d,e
20+0	132 b,c	121 b	127 b,c
20+60	126 b,c,d	110 b,c	118 c,d,e
20+120	120 c,d,e	106 c	113 d,e
40+0	125 b,c,d	111 b,c	118 c,d,e
40+60	114 d,e	107 c	111 e
40+120	106 e	91 d	99 f
40+120 (alt. years)	129 b,c	115 b,c	122 b,c,d

[1] Returns within columns followed by the same letter are not significantly different at the 5- percent level, using Tukey's studentized range test (HSD). A $6-per-hour labor charge and 7 percent interest rate were used for the returns calculation.

ment incurred approximately half the cost of the 40+120 annual application.

Yields

Two yield analyses were completed during this study. First, average treatment yields for the eleven-year period (1979-1989) were tested for statistical significance using analysis of variance (ANOVA). The second yield analysis was conducted to determine whether or not there were any long-run trends. Simple linear regression analysis with yield as the dependent variable and year as the independent variable was used for this purpose.

The eleven-year average yields by treatment and crop are reported in Table 3. No treatment significantly explained the variation in corn or soybean yields. In the regressions analyzing the effect of time on yield for each treatment, none of the estimated coefficients for time was significant.

Returns to land and management

We analyzed economic returns using yearly average Iowa corn and soybean prices received by farmers and the cost assumptions outlined previously. Annual returns to land and management were calculated by subtracting production costs, including labor, from gross revenues. Average annual returns were tested for statistical significance using an ANOVA procedure. Following determination of significance, Tukey's multiple range test (HSD) was used for testing statistical differences among treatments. Average annual returns to land and management for the corn and soybean crops alone and the corn-soybean rotation by treatment are presented in Table 4. Because yields were not significantly different, returns per acre to land and management were directly related to the cost of the treatment. That is, the higher the P and K costs, the lower the net returns.

The control (0+0) had the highest returns for both corn and soybeans at $149 and $136 per acre, respectively. Only corn returns to the 0+60 were not significantly lower than those to the control treatment. The 40+120 returns to the corn-soybean rotation were the lowest among all treatments at $99 per acre, significantly lower than any other treatment.

Discussion

Initial soil test levels were high and very high in P and K, respectively. With this in mind, we make a number of conclusions based on this study. First, the maintenance application of 20+60 would cost $24/acre more than a zero application treatment. These are the costs of maintaining the soil in the high to very high range. Applications should not be above these rates, given soils testing very high. For example, annual fertil-

ization of 40+120 would cost an additional $21/acre and would be more than the crop could use.

Second, soils testing very high do not need to be maintained annually. That is, the reduced rates with the sufficiency approach would be agronomically and economically sounder than the maintenance approach. This is not to say that fertilization can be discontinued indefinitely without adverse effects on crop yields. Rather, discontinuing or drastically reducing application rates while soil test levels are very high in P or K can be accomplished without significantly affecting yields. Therefore, the savings in fertilizer purchases would increase returns.

Third, corn and soybean yields did not significantly respond to any annual application of P and K in this study. It seems that adequate residual P and K prevented any yield differences associated with P and K levels over the eleven-year period. The economic savings could reach $45/acre, depending on the initial application rate. Further research is needed to determine if sufficiency level recommendations can be lowered in some cases.

In summary, researchers must continue to determine if further reductions in fertilization can be realized without reducing yields. Extension workers must continue to develop ways to help farmers realize the usefulness of soil testing. Farmers must carefully evaluate their fertilization needs in conjunction with soil test results. Together, a more sustainable approach to P and K fertilization for corn and soybeans may be attained.

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LETTERS

Sustainable community must address broad issues

The article by MacRae, et al., "Policy, programs, and regulations...in Canada" (*AJAA* 5(2), 76-92) raises a number of issues which need to be addressed by the sustainable agriculture community. While one might hope to find some universality regarding the biophysical nature of sustainability, no one has, at this point, applied any cross cultural analysis to assess whether there might be universality to sustainability at a social and political level. For example, the authors cite the situation in Norway where government policy substantially shifted food production and dietary habits of the country. In other situations, Sweden has similarly been cited as a model for health care. Given the homogeneity of the populations in Scandanavia and socialist predilections of the government, it is questionable whether such a transference is feasible or even desirable in North America in general, or even Canada in particular.

Next, the authors have created an interesting paradox. On one hand, they are asking government to develop more flexibility and innovation in farm programs. On the other hand, they wish this government flexibility to be used to preserve existing farm and rural community models. Significant thought has been given to alternatives to current government policy, and little consideration has been given to creation of new community models which might be developed along biological and environmental boundaries as opposed to traditional political divisions.

Third, the authors set up an inherent bias against trade. Given their desire to maintain a static model of community, there may be some merit to this position. But one should note that North American prehistory shows that there were extensive trade networks across the continent which did not promot community destruction or consump tion of non-renewable resources. Th continent was discovered by European primarily because of interests in trad opportunities. Designing for maximun local self-sufficiency with the exclusio of imports (perceived to be luxuries b some personal standard) is particularl questionable when it is not clear ho to define "local".

The authors also ignore two critica points. First, there are many factor which have led to the current farm situ ation in Canada and the United State beyond direct legislation on agricu ture. This includes the increased mobi ity of persons, goods, and informatio In the U.S., the opening of the inte state system and the growth of ele tronic media have had much to do wit shifts in the rural economy.

Second, legislation is always a com promise with no guarantees that th benefits and restrictions will have th

intended outcomes desired. For example, there is evidence that sustainable agriculture, and even organic farming, can be implemented more profitably by large farming operations instead of the "family farms" advocated by many in the sustainable agriculture community.

A famous psychologist once said that it is difficult to get one's "NO" back. Every time one abrogates social responsibility by turning to government to redress problems, one has removed power from him or her self to control and direct his/her life and that of the local community. The Canadians might wish to tread lightly until they see how the recent legislation in the United States plays out in program implementation with regards to organic and sustainable agriculture.

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Response: I like some of the thoughts put forward by Abeles but am confused by others.

Abeles alludes to some interesting questions regarding the relationship between policy that respects agroecological principles and the homogeneity of the population. We did not discuss this in our paper, but it would be most interesting to see a conceptual analysis of whether public policy that supports agroecological diversity can satisfy the needs of an ethno-racially diverse population.

I also like Abeles' conclusions on the need for more thinking on new farm and rural community models. I don't believe, however, that our analysis implies preserving existing models. To hold such a position would be a contradiction of basic ecological principles. Nor do we conclude that only small and family farms can produce food sustainably. Although we did not discuss it at length, the regional land use implications of a policy of food self-reliance imply very different patterns of agricultural production, processing and distribution, and very different intra-community dynamics. This is a very important area for further work.

It is not clear to me how the author has come up with his interpretation of our trade analysis. We are not saying that there shouldn't be trade, but rather that international and interregional trade should respect ecological principles. Simply stated, once a region has satisfied (in an economic and biophysical sense) its own markets, excess can be exchanged with other areas. Canadian trade and trade policy have never been designed around this idea.

Finally, Abeles misinterprets the reason for focusing our discussion on the role of government in the transition to sustainable systems. We are definitely not saying that government has the only role to play in this process. Community and farm organizations must actively push governments to change their agricultural agenda. We believe our paper serves as a "road map" for the political work of these organizations.

Rod MacRae

Questions experimental design

"The on-farm research program of Practical Farmers of Iowa" [Volume 5(4)] focuses on experimental design and analysis, yet several astonishing errors occur in the paper.

Someone must have been sleeping to allow the figure on page 164 to go uncorrected. The drawing illustrates no replication, rather than three replicates, as stated in the legend.

The paper states that 6 or more replications are needed in this design. Such general statements are misleading. The number of replications required to detect significant differences is dependent on 1) the magnitude of differences between treatments, 2) the amount of variation among replicates, 3) the desired significance level, and 4) depending on one's philosophy of comparison, the number of treatments in the experiment. How could such a blanket statement go unchallenged?

When referencing the figure, the authors use the terms "blocks," "replicates," and "pairs" interchangeably. The analysis of the data will be different depending on the exact grouping of the treatments. If the treatments are arranged in true blocks or if more than two treatments are used, then an analysis of variance using F-tests is called for. If the treatments are grouped in pairs, then a paired t-test would be most appropriate.

Finally, the implication is made that long strip plots are suitable for all on-farm experiments. In the case of variety trials or herbicide tests, there are certain advantages. However, in the case of insect or disease management trials, large square plots may be more desirable since the target organism or management technique may not be static in space or time.

I am extremely pleased to read articles by farmers in *AJAA*, but in this particular case, some guidance from a competent reviewer was called for.

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Response: As the authors of the paper in question, and as technical editor responsible for its review, we appreciate Professor Pritts' taking the trouble to point out possible errors. However, we believe that, on closer examination, only one of his criticisms really qualifies as an error: the technical editor readily admits to somnolence in not catching the "Three Replications" legend, which should have read "Three Treatments."

The sentence about 6 or more replications being needed was not intended as a general statement. The right number of replications certainly does depend on all the things that Professor Pritts lists. In the paper, the statement in question was immediately followed by typical values of those very parameters (significance level, number of treatments, variance, etc.) for the experiments under discussion. We thought the statement would be understood in that light; that is, it obviously was intended to be taken in the context of the entire paragraph, not as a "blanket statement." Perhaps this would have

been clearer if instead of saying "in this design" the statement had read "for these experiments."

The argument about analysis of variance and an F-test being appropriate if there are more than two treatments, whereas a paired t-test is appropriate for two treatments, overlooks an important point: with two treatments, analysis of variance and a paired t-test are identical. The F-statistic in such a case is simply the square of the t-statistic, and the statistical significance of the observed difference between treatments is the same, regardless of which way it was computed.

Finally, the statement about the suitability of long strips was certainly not intended to refer to all on-farm experiments. In the paper, that statement began by citing the particular methodological research on which it is based. We took for granted that the reader would know to supply the qualifier "under the conditions of that research." (Not coincidentally, that research dealt with experiments similar to those discussed in the paper.) One might argue that such a qualifier should always be included when citing a research result, but commonly it is left unsaid, without causing any great misunderstanding.

Richard Thompson
Sharon Thompson
William Lockeretz

A sustainable agriculture requires broad approach

The commentary by Allen et al., *Integrating social, environmental, and economic issues in sustainable agriculture* (Volume 6, No. 1, page 34) was great. They clearly pointed out the existing imbalance between the search for specific on-farm strategies and the search for social, political, and economic structure for a sustainable agriculture. Lots of the former, little of the latter in our mainstream agricultural establishment.

Cultural, political, social, and ethical foundations for a sustainable agriculture *have continuously been proposed* by Wendell Berry, Wes Jackson, Marty Strange, Gene Logsdon, Donald Worster, Gary Nabhan, Robert Rodale.... These scholars have thoroughly outlined the basic assumptions that have lead (and are still leading) agriculture to its current degrading path, raised essential questions, and wrote about possibilities for an agriculture that cares for the land and the people. Many of us working to create a healthier agriculture have been inspired by them and yet, for some reason, they are not acknowledged in the cited literature by Allen et al. or many other papers related to rethinking of our agriculture, integrating sociology, ethics, and justice in agriculture.

The ultimate measure of the quality and effectiveness of our agricultural research, education, and service should be reflected in farmers' livelihood, resurrected rural communities, landscape restoration, and social and economic equity for people in the food system here and elsewhere.

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Response: Dr. Enshayan is quite right in citing the contributions of these writers--they have been among the first to influence the agricultural paradigm in the direction of sustainability. Our article was not intended as a comprehensive literature review, however, but an attempt to demonstrate that we need to move beyond the priorities of many sustainable agriculture programs newly established within agricultural institutions. Nonetheless, while we also acknowledge the seminal contributions of Berry, Jackson, Strange, et al., we think we need to go farther than they do in reconstructing agriculture in ways that will make it truly sustainable for all social groups. Their work focuses on the traditional American family farm as the beneficiary and ideal vehicle for sustainability. While this is an important focus, we believe it does not adequately encourage new agricultural forms that address the issues of the larger community which is a part of agriculture and is affected by it. Particularly overlooked is the need to reco figure race, class, and gender relatio in ways that allow everyone--includi women, people of color, the poor-- benefit equally from sustainable ag culture. This theme is elaborated in a article by Patricia Allen and Caroly Sachs in issue 13 of the journal *Scien as Culture.*

Patricia Allen, Debra Van Duse and Stephen Gliessman

Supreme Court Allows Localities to Regulate Pesticides

The U.S. Supreme Court ha ruled unanimously that the Federa Insecticide, Fungicide, and Rodenti cide Act (FIFRA) does not deny lo cal authorities the right to regulat pesticides. However, the Supreme Court reaffirmed the right of state to pre-empt local authority, if the choose; states that do not already have laws concerning local pesticid authority may now tackle the issue The decision applies only to loca regulation of the use and sale of pes ticides, not labeling, packaging, o initiation of health studies. The cas began in 1985 when a Christmas tre grower in Casey, Wisconsin, was de nied a permit for aerial spraying o pesticides on some of his land an sued the local government.

Correction

The textual references to Figures 2 and 3 were reversed in the article by Crews and Gliessman, "Raised field agriculture in Tlaxcala, Mexico: An ecosystem perspective on maintenance of soil fertility," Am. J. Alternative Agric. 6:9-16. We regret the error.

A survey of organic produce purchases and related attitudes of food cooperative shoppers

Barbara J. Goldman and Katherine L. Clancy

Abstract. *We surveyed shoppers at a food cooperative in New York state to measure the relationship between organic produce purchases and attitudes related to pesticide use in agriculture, food costs, and other factors affecting produce buying. Two-fifths of the co-op shoppers surveyed usually or almost always purchased organically grown produce, and one-third were somewhat or very likely to pay 100 percent more than conventional produce for residue-free produce. Those who usually or almost always purchased organic produce were less concerned than other shoppers about price when they shop for produce, had higher levels of concern about food safety, and were less concerned about insects and surface blemishes on produce. There was no relationship between income and frequency of organic purchases. Most shoppers were concerned about pesticide residues in produce, but a high level of concern appeared necessary to affect the frequency of organic purchases. In their support of organic agriculture, respondents ranked environmental protection higher than consumer protection. Educators should emphasize both the environmental and food safety benefits of organic farming to consumers.*

Key words: food safety, pesticide residues, consumer research, organic farming

Introduction

Several regionally and nationally representative surveys have found that consumers are concerned about pesticide effects on wildlife and about pesticide residues in drinking water and the food supply (Jolly et al., 1989; Schutz et al., 1989; Zind, 1989; Food Marketing Institute, 1987; Sachs et al., 1987; Hawkes and Stiles, 1986; Yarbrough and Yarbrough, 1985; Penner et al., 1983). Consumers have greater concern for pesticide residues than bacterial contamination, food additives and preservatives (Jolly et al., 1989; Smallwood, 1988). Van Ravenswaay (1988) has hypothesized that this high level of concern may be due to perceptions that the health risks are severe, that the benefits of pesticide use are small, and that consumers have little control over their exposure to them.

Because of several problems with EPA procedures for setting residue tolerances, few convincing assessments of the actual consumer risk have been undertaken. The risk to the average consumer does not appear to be striking, especially relative to other food safety risks. Over one-half of the produce items tested by the FDA are residue free, and a very small proportion of those tested are found to violate residue limits. However, much of the consumer concern appears to focus on whether the tolerance levels are safe, rather than whether levels are under the legal limits (Gianessi and Greene, 1988). Many consumers do perceive a health risk from pesticide residues in produce, especially for certain vulnerable subgroups of the population. Supporting this perception is a report criticizing the EPA for not considering infants' and children's sensitivity to toxins and their restricted diet when it sets tolerances for pesticides in food (Blair, 1989).

Despite these concerns, most shoppers do not buy organically grown produce. A nationwide survey in 1989 found that only 28 percent of respondents sought out organically grown or residue-reduced produce as a result of media reports regarding the risks of pesticides (Organic Gardening, 1990). A survey of Californians conducted in 1987 found that only 23 percent of respondents frequently look for organically grown foods when they shop (Jolly et al., 1989). In two 1984 and 1985 regional surveys, correlations between pesticide concern and intended action, such as altering purchases, were weak (Yarbrough and Yarbrough, 1985; Sachs et al., 1987).

The lack of a strong correlation between pesticide concern and produce purchases is not altogether surprising. Although particular attitudes are often assumed to lead to particular behavior, the social psychological and nutrition literature provides little data in support of this assumption (Sims, 1980). In addition to being influenced by concern over pesticides, changes in purchases probably are held back by the lack of alternatives or their higher price. Also, some consumers may realize that the incidence of pesticide contamination on produce generally is low, although they could not know which particular articles have residue levels at or below EPA tolerances. A review of the literature that follows points out several other consumer attitudes that may work against buying of organic produce.

Demand for alternatives may be adversely affected by the perceived benefits of pesticide use in agriculture, at home, and on public land (Sachs et al., 1987). The perceived benefits of pesticide use in agriculture include high-quality produce (with quality defined by taste and appearance) and lower costs (Penner et al., 1983; Hawkes and Stiles, 1986). Con-

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sumers appear to make a tradeoff between the benefits and risks of pesticide use as shown by the finding that a majority (80 percent) of Pennsylvanians surveyed in 1984 were somewhat or very likely to purchase minimally sprayed produce unless it had surface blemishes (Sachs et al., 1987). When respondents in a survey conducted for the Alliance for Food and Fiber, a produce industry consortium, were asked to state a level of agreement with the statement, "I'd rather eat food not treated with pesticides even if it means there are bugs in it," 62 percent disagreed (24 percent) or strongly disagreed (38 percent) (P. Jones, Executive Director of AFF, private communication, 1988).

Pimentel et al. (1977) have stated that consumers are prejudiced against insects. A survey of the public in California showed that most consumers who are concerned about the dangers of pesticide use are willing to eat produce sprayed with pesticides if it is insect free (Hawkes and Stiles, 1986). Perhaps some consumers do not distinguish harmless herbivores on produce from health hazards posed by rodents, insects, or bacteria because of unsanitary processing and storage conditions of meat and grain.

Grading standards and decreasing filth tolerance levels may have raised the expectations of consumers regarding cosmetic appearance and insect parts to a level which is antithetical to optimal food safety (Clancy, 1988). Pesticide use has increased as a direct result of reduced defect action levels and increased emphasis on cosmetic appearance by food processors, wholesalers, and retailers (National Research Council, 1989; Pimentel et al., 1977). The average additional insecticide use on fruits and vegetables to meet cosmetic standards has been reported from as low as 10-20 percent (Pimentel et al., 1977) to as high as 60-80 percent for some crops (Feenstra, 1988).

Very little is known about consumer attitudes towards the quality of organically grown produce. What data are available imply that apperance may affect organic purchases to some extent, but the influence does not seem to be large for most consumers. One reason may be that organically grown produce is sometimes marketed under the same quality standards as conventionally grown produce. Respondents to one California study who purchased organic produce were generally satisfied with its quality. If they were dissatisfied, the most frequent reason was appearance (Jolly et al., 1989). Forty-two percent of the respondents in a 1989 nationwide survey felt that organic fruits and vegetables look about the same as those grown without chemicals, and only 21 percent of respondents felt that organics look worse (Organic Gardening, 1990).

In summary, studies published to date have compared consumer attitudes towards pesticide use and perception of risk to willingness to purchase organic produce. These studies have found that consumers are more accepting of pesticide residues in produce if the produce is also free of surface blemishes and insects. A survey of Californians compared consumer attitudes towards organic foods with actual organic purchases and concluded that shoppers who purchased organic food were generally satisfied with its appearance but that its higher price and lower availability deterred some shoppers from purchasing it (Jolly et al., 1989). Although the relationships between actual organic produce purchases and general attitudes towards appearance, produce price, and concern over pesticide residues have been studied, no research to date has looked at specific consumer attitudes towards insects and surface blemishes as they relate to actual organic produce purchases. By quantifying the frequency of organic produce purchases in a population with fairly wide exposure and interest in organics, we were able to determine if shoppers' attitudes towards produce price and appearance, including attitudes towards seeing occasional insects or surface damage, corresponded to the frequency of organic produce purchases.

Data collection, survey instrument, and data analysis

We surveyed shoppers at a food cooperative that is the largest purveyor of organic produce in upstate New York. Food cooperative shoppers differ fr the general population. They pre nutrient-dense foods and are more int ested in the political aspects of food p duction (Irish and Ries, 1987; Fjeld al., 1983). The study group was cho despite these biases in order to sampl population exposed to a fairly wide sel tion of organic produce.

Depending on the product and t season, organically grown produce this co-op was from 25 percent to o 100 percent more expensive than c ventionally grown produce at the time this survey. This higher cost is par related to the higher labor costs a smaller size of many organic farms. T immaturity of the organic market in t northeast is also important. Organic p duce is not as expensive on the w coast, where the supply is more abu dant, the distance traveled to market shorter, and the distribution network better organized.

We conducted the survey in June a July, 1988. The actual selection of spondents took place during a nine-d period beginning June 23rd and endi July 1st. In order to equally repres morning (10 a.m.-2 p.m.), afternoon p.m.-6 p.m.), and evening (6 p.m.-9 p.m shoppers, sampling occurred at ni pre-selected time periods. Sampli times were randomly chosen fr twenty-seven possible periods over ni days. The researcher approached eve other shopper on one checkout line un four hundred shoppers agreed to be s veyed. Five shoppers refused to parti pate. Respondents were asked to ta home a questionnaire and return it mail in a pre-addressed, stamped en lope. The initial contact was followed two mailings: a reminder postcard f days after initial contact and a repla ment survey mailed as needed ten da after the initial contact (Dillman, 197 Three hundred and fifty shoppers sponded, yielding a response rate of 8 percent.

The survey consisted of an eleven-pa questionnaire that requested dem graphic information and responses items designed for the construction five attitude scales: price consciousne pesticide concern, appearance conce insect concern, and surface blemish c

cern. We expected these to be relevant concerns, based on the consumer survey literature. Four- or five-point Likert scales were used for each item in an attitude scale. The score for each scale was the sum of the appropriate item scores. To eliminate test bias that can result when a respondent answers a string of similar attitude questions, the questions were worded positively and negatively to elicit responses at both ends of the Likert scale. Scores for certain items were reversed when necessary so that items were in the appropriate direction. In addition, not all items in a given scale had the same number of response categories. In scales that had items with four and five response categories, item scores were multiplied by the appropriate factor to give a common scale with a range from 4 to 20. Finally, each total score was linearly transformed to give a common scale from 0 (not concerned) to 100 (concerned).

Cronbach's alpha was employed to test the reliability of the single score resulting from the summation of all of the items in each scale (Carmines and Zeller, 1980). Questions about the importance of general appearance (size, shape, color, and freshness) in the purchase of fresh fruits and vegetables were included in the survey but did not form a reliable scale.

To measure organic produce purchases, we asked respondents, "In general, when you shop for produce, how often do you buy the organically grown produce that is available?". Shoppers responded to a five-point Likert scale: almost always, usually, sometimes, once in a while, or almost never. The chi-square statistic was used to compare relationships between the frequency of organic produce purchases and attitude scale scores.

A series of questions was included to measure willingness to purchase residue-free produce rather than conventional produce at several different price levels and with several different appearance characteristics. Respondents were asked to indicate how likely they would be to buy produce labeled residue free rather than produce labeled conventional residue that cost the same, under each of the following conditions: if they looked the same; if the residue free was less brightly colored, irregular in shape, or smaller in size; if the residue free had surface blemishes; and if the residue free had a bug in it. These four questions were repeated with the residue free costing 50 percent more than the conventional and again with the residue free costing 100 percent more. Respondents answered a five-point Likert scale from very unlikely to very likely for each question. Conventional produce was defined for respondents as produce with residues up to the legal limits set by government. Finally, we included a question on the ranking of various benefits of organic agriculture, including consumer safety, worker safety, environmental quality, and energy conservation.

Table 1. Demographic and Descriptive Characteristics of the Co-op Sample

Female:	62%
Age (mean):	35 yrs ± 12 (S.D.)
(range):	17-88 yrs
Students:	27%
Some college education:	93%
Completed more than 16 yrs. of school	55%
Vegetarian or semi-vegetarian:	34%
Household income $20,000 and greater	49%
Average weekly food expenditures/person	$60 ± $28 (S.D.)
Purchase 75-100% of their groceries at the co-op	49%

Table 2. Percent responses to price consciousness questions.

	Price Consciousness[ab]				
	low				high
	1	2	3	4	5
1. When you shop for produce in grocery stores, how often does price influence which fruits and vegetables you buy?	5	23	49	23	c
2. Rank the importance of price relative to other factors (personal preference, nutritional value, appearance, how it was grown, pesticide residues, locally grown, the likes and dislikes of others who you live with) that are important to you when you shop for produce in grocery stores?	16	38	19	19	8
3. How often does price influence your decision to buy or not to buy organically grown produce?	5	31	30	34	c
4. Rank the importance of price relative to other factors (surface blemishes, freshness, availability or selection, certification, locally grown, the possibility of consuming pesticide residues) that influence your decision to buy organic produce.	9	40	20	31	c

[a]coefficient alpha = 0.81
[b]Co-op shoppers responded to the following scales:
For 1 & 3; 1=almost never, 2=occasionally, 3=frequently, 4=almost always
For 2; 1=least important to 5=most important
For 4; 1=least important to 4=most important
[c]These questions had four response categories
Price consciousness scale total scores on a scale of 0 (no price consciousness) to 100 (high price consciousness) have a mean total score of 57 pts. (range = 20 – 86 pts).

Results

Demographic characteristics of the sample are presented in Table 1. The majority of the sample was female, with a mean age of 35 years. Twenty-seven percent were students, and 34 percent were vegetarian. All but 6 percent of the respondents had some college education, and 55 percent had completed more than 16 years of school. Half of the respondents (49 percent) had household incomes (reported in categories) of $20,000 or greater, compared to 64 percent of the general population in the northeastern

U.S. (U.S. Bureau of the Census, 1987). Vegetarians and shoppers aged 30-49 years tended to purchase organic produce more frequently than others. Those who were 40-49 years old reported higher total household income levels than other shoppers, attached less importance to price, and were more concerned about pesticides. For the sample as a whole, the purchase of organic produce was not related to income categories or total food expenditures.

Twenty-three percent of the sample said that they purchased organic produce almost never or once in a while, 36 percent sometimes did, and 41 percent did so usually or almost always. On a scale of 0 (not concerned) to 100 (highly concerned), survey respondents were moderately price conscious when shopping for produce (mean total score = 57); modestly concerned about insects (mean total score = 31) and surface blemishes (mean total score = 28); and highly concerned about pesticide residues (mean score = 70 points). Responses to the questions in each scale are listed in Tables 2, 3, 4, and 5. Values were rounded to the nearest whole digit and may not add up to 100 percent. As shown in Table 3, most respondents disagreed with statements that insects are harmful to human health. However, the presence of insects on produce was at least somewhat important to 75 percent of the sample. Respondents who said that they purchased organic produce usually or almost always (about two-fifths of the sample) were less price conscious when they shopped for produce ($x^2 = 85.8$, $p<0.001$), less concerned about insects ($x^2 = 23.3$, $p<0.001$) and surface blemishes ($x^2 = 11.0$, $p<0.02$) and more concerned about pesticide residues than other shoppers ($x^2 = 127.4$, $p<0.001$).

Attitudes towards specific aspects of produce appearance, towards insects, and towards surface blemishes affected respondents' stated willingness to pay 50 percent or 100 percent more for residue-free produce. As shown in Figure 1, nearly all respondents were very likely to buy residue-free produce if it looked and cost the same as conventional. A few respondents (8 percent) were not very likely to purchase residue free with the

Table 3. Percent responses to questions in the insect concern scale.

	Insect Concern[a,b] low 1	2	3	4 high
			percent	
1. Insects on fruits and vegetables in the U.S. carry diseases that are harmful to human health.	19	53	16	11
2. People that you know have gotten sick from eating produce with insects on it.	40	40	17	2
3. Farmers should not try to eliminate all insects from fruits and vegetables.	28	47	13	8
4. I would prefer to eat produce that may have insects rather than produce that may have pesticide residues.	32	44	15	7
5. The presence of insects decreases the nutritional value of produce.	29	55	9	5
6. The presence of a few insects on produce indicates insufficient insect control.	26	55	14	5
7. The presence of insects on produce indicates it has been improperly or unsatisfactorily inspected.	16	53	21	9
8. When you think about the appearance of fresh fruits and vegetables how important to you are insects?	5	19	29	24
9. How likely would you be to buy a head of broccoli that might have a worm in it?	23	37	14	17

[a]coefficient alpha = 0.80
[b]Co-op shoppers responded to the following scales:
For 3&4; 5=strongly disagree 4=disagree 3=no opinion 2=agree 1=strongly agree
For 1,2,5,6&7; 1=strongly disagree 2=disagree 3=no opinion 4=agree 5=strongly agree
For 8; 1=not at all important 2=slightly important 3=somewhat important 4=considerably importa
5=highly important
For 9; 1=very unlikely 2=somewhat unlikely 3=not sure 4=somewhat likely 5=very likely
Insect concern scale total scores on a scale of 0 (no insect concern) to 100 (high insect concern) have a mea
total score of 31 pts. (range = 14 – 62 pts.).

Table 4. Percent responses to questions in the surface blemish concern scale.

	Surface Blemish Concern[a,b] low 1	2	3	4 high
			percent	
1. When you think about the appearance of fresh fruits and vegetables how important are surface blemishes (rough patches and spots on the skin or peel of fresh fruits and vegetables)?	7	34	36	17
2. How likely would you be to buy an orange with surface blemishes?	38	44	5	10
3. How often do surface blemishes influence your decision to buy or not to buy organically grown produce?	26	56	15	3
4. Surface blemishes such as rough patches and spots do not harm human beings.	37	50	7	5
5. Unblemished produce is more nutritious than blemished produce.	41	46	9	4
6. Slight surface blemishes decrease the value of produce to you.	24	47	9	18

[a]coefficient alpha=0.78
[b]Co-op shoppers responded to the following scales:
For 1; 1=not at all important 2=slightly important 3=somewhat important 4=considerably important 5=highly important
For 2; 5=very unlikely 4=somewhat unlikely 3=not sure 2=somewhat likely 1=very likely
For 3; 1=almost never 2=occasionally 3=frequently 4=almost always
For 4; 5=strongly disagree 4=disagree 3=no opinion 2=agree 1=strongly agree
For 5 and 6; 1=strongly disagree 2=disagree 3=no opinion 4=agree 5=strongly agree
[c]This question had four response categories
Surface blemish concern scale total scores on a scale of 0 (no insect concern) to 100 (high insect concern) have a mean total score of 28 pts. (range = 14 – 63 pts.).

Table 5. Percent responses to pesticide concern questions.

	Pesticide Concern[a,b]				
	low				high
	1	2	3	4	5
	percent				
. How concerned are you about eating fresh fruits nd vegetables with pesticide residues?	2	12	26	32	28
. How often does your concern about pesticide esidues influence which fruits and vegetables ou buy?	20	26	22	17	15
. How often does your concern about the possibility f consuming pesticide residues influence your ecision to buy or not to buy organically grown roduce?	12	29	34	24	c
. How much danger do you feel there is to the erson who eats fresh fruits and vegetables that ave been sprayed or dusted with pesticides?	1	9	45	35	d
. I would prefer to eat produce that may have nsects rather then produce that may have esticide residues.	1	7	15	44	32
. The continued use of pesticides will produce ancer and leukemia in humans.	1	3	22	44	30
. The legal level of residues allowed in produce s too high for safety.	1	2	27	39	31
. The government should try to eliminate all esticides residues on fresh produce.	2	12	12	40	35
. Farmers should try to eliminate all pesticide esidues on fresh produce.	0	6	12	45	37
0. Although trace amounts of some pesticides are ound in foods these represent little hazard to uman health.	1	8	22	46	23

coefficient alpha = 0.85

Co-op shoppers responded to the following scales:

For 1; 1=not concerned 2=slightly concerned 3=moderately concerned 4=considerably concerned 5=highly concerned

For 2: 1= almost never 2=about 25% of the time 3=about 50% of the time 4=about 75% of the ime 5=almost always

For 3; 1=almost never 2=occasionally 3=frequently 4=almost always

For 4; 1=none 2=very little 3=some 4=a great deal

For 5,6,7,8&9; 1=strongly disagree 2=disagree 3=no opinion 4=agree 5=strongly agree

For 10; 5=strongly disagree 4=disagree 3=no opinion 2=agree 1=strongly agree

This question had four response categories.

9% of responses = 'don't Know', data not shown in table.

Pesticide residue concern scale total scores on a scale of 0 (no insect concern) to 100 high insect concern) have a mean total score of 70 pts. (range = 22 – 92pts.).

ame price and appearance as conven- ional, probably because they were un- onvinced that it is better than conven- ional. The percentage who were very ikely to purchase the residue free de- reased by approximately one-third if he residue free looked irregular (less rightly colored, irregularly shaped, or naller) or had surface blemishes and wo-thirds if the residue free had a bug n it. As shown, for all three price levels, illingness to buy residue-free produce as greatest when the residue free ooked the same as conventional and east when the residue free had an insect n it.

Regarding attitudes towards produce ppearance, 83 percent of respondents lt that appearance frequently or almost always influenced their produce purchases. Two-thirds of respondents believed that pesticide use improves produce appearance. Forty-five percent felt that organic produce usually looks worse than conventional produce, 12 percent thought organic produce looks superior, and 32 percent thought there is no difference. Although many survey respondents believed that organic produce looks inferior, they were no less likely to purchase it.

Respondents were asked to state the importance to them of a list of reasons frequently given in support of organic agriculture. Co-op shoppers did not feel that consumer protection from pesticide residues was the most important reason to support organic agriculture. On a scale of 1 (least important) to 4 (most important), protection of wildlife and water supplies from pesticide contamination was most important (mean score = 3.0). This was followed by protection of drinking water supplies from fertilizer contamination (2.3), protection of consumers from pesticide residues in food (2.3), conservation of non-renewable natural resources (2.2), protection of farm workers from pesticide exposure (2.2), and lastly, preservation of the balance of nature on the farm (2.0).

Discussion

The purpose of the study was to identify attitudes that are related to organic produce purchases in this select population of organic produce buyers. The results show that, compared to shoppers who purchase organic produce less often or not at all, co-op shoppers who usually or almost always purchase organic produce are less concerned about surface blemishes and insects in produce, more concerned about pesticide use, and less price conscious when they buy produce.

Survey respondents at this co-op resemble members of other food co-ops in their high level of education, their preference for vegetarianism, and their positive attitudes towards organically grown food (Irish and Ries, 1987; Ehlers and Fox, 1982; Fjeld et al., 1983). Their education level was even higher than that reported for another co-op; 55 percent of the sample had at least some post-graduate education compared to 36 percent reported in a midwest university community (Irish and Ries, 1987). The proportion of students was lower and the mean age was higher than in studies of similar co-ops (Irish and Ries, 1987; Ehlers and Fox, 1982). The frequency of organic produce purchases was invariant of the descriptive characteristics given in Table 1. Similarly, Jolly et al. (1989) found that organic food shoppers did not differ from other shoppers in sex, age, or income. No other data are available on the demographics of organic food buyers in the general population.

The higher price of organic produce obviously has an effect on purchases; at this co-op organic produce cost 75 per-

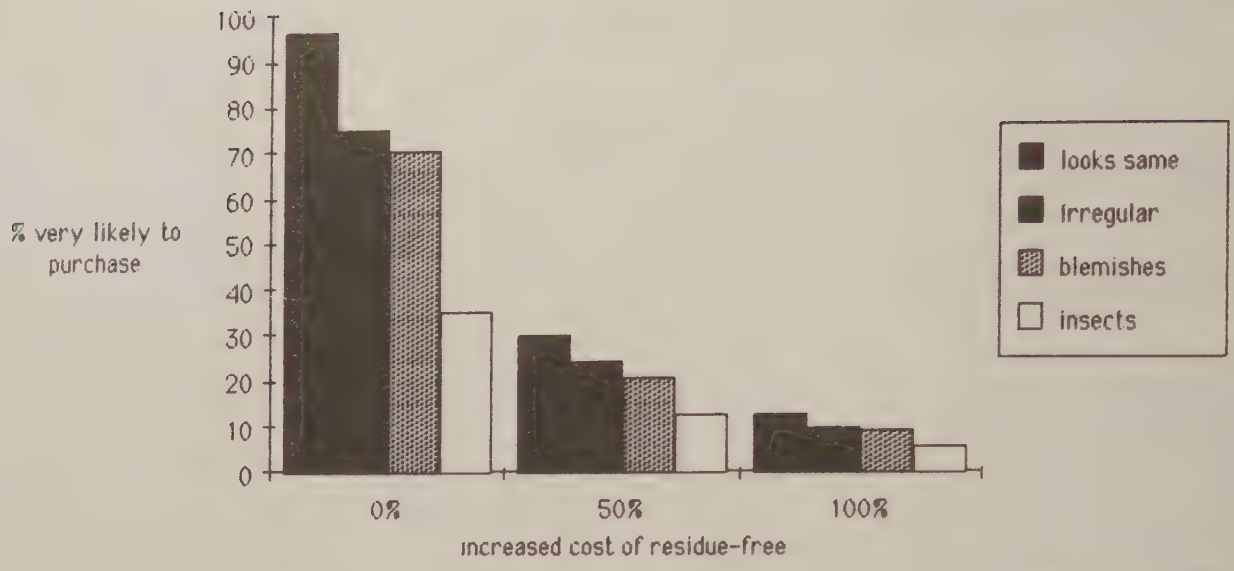

Figure 1. Willingness to buy residue-free produce.

cent more than conventional on the average, and price consciousness was very negatively related to organic purchases. Yet despite the relatively low incomes reported by shoppers in this study, many respondents purchased the organic produce and stated that price is less important than nutritional value. The apparently low importance placed on price is not peculiar to the co-op population. The survey of organic produce purchasers in California mentioned above (Jolly et al., 1989) found that attitudes towards food safety, nutrition, and flavor all were more important than attitudes towards price for food purchases in general.

There are trends in the general population that help to explain this paradox. First, because of a decrease in the number of blue-collar workers and increase in the number of two-earner families, there has been an increase in real disposable income (Putnam,1990). When food costs are a smaller percentage of household income, people are willing to spend more money on food. In the co-op population, however, willingness to spend more for organic produce occurs despite the lower incomes reported in general. Thus, affluence probably does not explain the fact that many co-op shoppers purchase organic foods. It is more likely that the high education level of co-op shoppers is important. Several investigators have found a positive relationship between diet quality and education (Axelson, 1986). Also, as the nutritional quality of the diet increases, food costs increase (Axelson, 1986). Because of their higher education level, many co-op shoppers may be less sensitive to income in spending for food. In addition, the greater importance they place on food safety, nutrition, and protection of the environment compared with price and appearance probably underlies their willingness to spend more money on organic produce.

The appearance of a food item is important to shoppers (co-op and others) (Blair and Sachs, 1988; Woman's Day and Food Marketing Institute, 1980), but very little is known about consumers' attitudes towards the appearance of organically grown produce. Co-op shoppers were split on this point: 45 percent believed organic produce looks worse; 32 percent thought there was no difference. In contrast, only 21 percent of respondents in a national survey believed that organic produce looks worse than conventional produce (Organic Gardening, 1990). It is not surprising that shoppers in the northeast, who are probably exposed to out-of-season organic produce, would tend to be critical about its appearance. Freshness was, in fact, very important to most co-op respondents in this study. Likewise, when survey respondents in California were asked about the importance to them of several characteristics related to choosing ganic foods, freshness was more imp tant than health benefits, nutrition, en ronment, flavor, and appearance a second only to safety (Jolly et al., 198

Although many co-op shopp judged that organic produce looks in rior, this attitude was not related to ganic purchases. Likewise, other data dicate that the appearance of orga foods is not an important consumer is (Jolly, et al., 1989; Organic Gardeni 1990). However, in this study, respo ents' acceptance of insects and surf blemishes on produce was very positiv related to organic purchases, and a cl relationship was seen between spec attributes of produce appearance and spondents' stated willingness to p chase residue-free produce. Despite fact that concern about pesticide r dues was greater than concern about s face blemishes and insects in this stu co-op shoppers were less willing to residue-free produce that was brightly colored, smaller or irregula shaped, or had surface blemishes or sects. Thus, in the tradeoff between p duce appearance and pesticide resid respondents apparently placed a hig priority on the elimination of distast but harmless materials from foods t on the possible health and safety r from pesticide use.

Co-op respondents were less c

erned about the effects of insects in pro-
uce on human health than about the
ere presence of insects. It is possible
at attitudes about insects in food may
e more closely related to attitudes about
urity/impurity than health. We did not
etermine the actual number of insects,
any, on organic produce at the co-op or
co-op shoppers associate insects with
rganic foods. Thus, we cannot further
xplain the relationship observed be-
ween attitudes towards insects on pro-
luce and organic produce purchases. Be-
ause of the food co-op bias in the
resent study, concern over insects and
urface blemishes would be expected to
e higher in the general population and
ay act as a deterrent to the purchase of
rganic produce.

Marshall (1974) stated that organi-
ally grown foods serve two consumer
eeds: to maintain environmental qual-
y and to provide foods without the po-
ential of added chemical toxicity. More
o-op shoppers endorsed organic agri-
ulture for its protection of wildlife and
rinking water supplies than for con-
mer protection. This conclusion is
rawn from a single survey question that
sked respondents to rank a list of six
opular reasons given in support of or-
anic agriculture. The rankings did not
orrelate with other survey parameters
ecause almost every respondent sup-
orted all six reasons. The emphasis
laced on environmental quality is simi-
r to findings from other studies (pub-
shed before media reports on Alar and
oung children) that showed consumers
California, New York, and Pennsylva-
ia were more concerned about the ef-
cts of pesticide use on wildlife and
rinking water than about the health
azards resulting from consuming pesti-
de residues in produce (Hawkes and
iles, 1986; Sachs et al., 1987; Yar-
rough and Yarbrough, 1985). Vogt-
ann (1988) reported that West Ger-
ans also were more interested in
cologically sound agricultural practices
an produce that is completely free of
sticide residues.

In this study population, a high level
pesticide concern appears to be neces-
ry to motivate shoppers to purchase
ganic produce frequently. Nearly all
-op respondents (98 percent) were at least slightly concerned about eating fresh fruits and vegetables with pesticide residues, but only about one-third were highly concerned. Only those shoppers with moderate to high concern usually or almost always purchased organics. This occurred despite the higher ranking for protection of environmental health versus human health.

Among the general population, the effect of food safety concern on consumer demand apparently is temporary. Supermarkets that began advertising organic produce following media reports about Alar and children discontinued it several months later, citing supply problems, lagging sales, and high costs as the reason (The Packer, 1990; Community Nutrition Institute, 1990). The price of organic produce seems to reduce demand in the long run.

The results of this study indicate that some consumers are more likely to purchase organic produce than others, at least in the co-op population, and that sustained high levels of food safety concern may be necessary to increase and stabilize demand. Furthermore, these results indicate that consumer attitudes towards insects in produce may negatively affect the strength of the market for organics. It is important to recognize that a greater consumer understanding of the costs and benefits of food production systems might increase markets. The inconsistent demand for organic foods may relate to an inconsistent attitude about residues, and consumer attention could be induced by appealing to environmental consciousness. It has been said that educated consumers need to make food choices that not only enhance their own health but also contribute to the protection of our natural resources (Gussow and Clancy, 1986). For these reasons, nutritionists and organic agriculture advocates need to make a greater effort to link organically grown produce to sustainable agriculture and environmental quality, in addition to food safety.

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SPECIAL REPORT

Conference on ecology, sustainable agriculture, and EPA

The role of ecology in developing a sustainable agriculture was the main theme of a conference held in Arlington, Virginia, July 22-23, 1991. Sponsored by the U.S. Environmental Protection Agency (EPA) and the Institute for Alternative Agriculture, the conference emphasized discussions of the current and future role of EPA in conducting research on sustainable agriculture.

The rationale for this conference stemmed from the contribution of agriculture to many of the environmental problems for which EPA is seeking solutions, e.g., nonpoint source pollution, contamination of ground water, air toxics, and loss of biodiversity. EPA's new emphasis on prevention rather than mitigation of environmental problems makes the potential environmental benefits of sustainable agriculture attractive to the Agency. EPA's growing expertise in ecology, combined with a recognition of the importance of ecological knowledge as a foundation for sustainable agriculture, led to the conference theme.

The first day of the conference consisted of ten invited presentations followed by a panel discussion. Topics included the social, economic, and political context of sustainable agriculture; definition and measurement of ecological sustainability; and ecological research at different spatial scales. The second day featured presentations on EPA agricultural research programs, current and proposed, and agroecological research and extension efforts of USDA. The conference concluded with small group discussions of research needs and approaches.

The key message coming out of the conference was that, while ecology has great potential for contributing to the development of a sustainable agriculture, success depends upon attention to the full context within which sustainab agriculture functions. An ecological based management scheme which ban rupts the farmer is not sustainable. R search results with which farmers feel affinity or ownership will probably n be implemented. Agriculture is mul disciplinary, and ecologists can most fectively contribute to sustainable ag culture as members of multi-disciplina research teams which include farme and on-farm research.

The disciplinary complexity of su tainable agriculture was illustrated the responses to a question directed a panel of speakers: "What one indicat of agricultural sustainability would ea panelist recommend?" Answers cluded:

- ratio of soil erosion to soil formati
- trend in average age of farmers
- nematode demographics
- connectivity of landscape elemen
- net farm income
- water quality

The panelists emphasized that no s gle indicator would suffice as a measu of sustainability--more complex indic need to be developed. Identifying a testing indicators of ecological conditi to serve as components of these broad indices needs to be a research priority agroecology.

Two other general research priorit in agroecology identified by the parti pants were long term (>5 years) a large-scale (watershed/landscape) stu ies. The majority of current research sustainable agriculture focuses on plo fields, or farms, and long-term fundi is rare. However, most of the envir mental issues associated with agricult are manifested at large scales. Meas able changes in water quality, soil qu ity, biodiversity, and other environm tal indicators in response to n agricultural practices may take a dec or more to occur. The only way to fu

(continued on page 104)

Information requirements of reduced-chemical production methods

William Lockeretz

Abstract. *Systems that reduce the use of fertilizers and pesticides are commonly said to do so by greater use of information and ecological understanding. However, this plausible proposition has not received much empirical examination. Different possible roles of information have not been clearly differentiated: in the development of new methods, in the farmer's decision whether to adopt them, and in their continued use. Also, the additional work that might be needed to handle information in reduced-chemical systems often is not distinguished from the need for greater management ability. Typical procedures for evaluating the performance of alternative systems do not give enough attention to farmers' management ability and use of information. This is also true for research on conventional systems, even though in such systems information and management are not usually considered to have such a critical role.*

Key words: reduced-chemical systems, agroecology, farmers' management ability, fertilizers, insecticides, irrigation, soil testing, insect scouting, research methods

Introduction

Production methods to reduce agriculture's use of fertilizers and pesticides are already being used in great variety, and many others are receiving serious research attention (Wagstaff, 1987). These methods are as divergent as scouting to decide whether an insecticide application can be omitted, improved cultivating techniques that reduce the need for herbicides, more efficient use of livestock manures, and leguminous cover crops to supply nitrogen to the following crop.

In recent years many authors have suggested common elements that link this wide variety of techniques. A frequent theme concerns the role of information and decision-making. Whatever the unifying label, such as *sustainable* or *alternative*, reduced-chemical methods invariably are described as using information, management ability, and ecological understanding to replace material inputs (Francis and King, 1988). For example, Stinner and House (1987) say that "High chemical input practices conceal and depreciate the importance of ecological processes... As pesticides, fertilizers, etc. are reduced, greater knowledge of the interactions occurring in agroecosystems is required for success."

Without a doubt, reduced-chemical methods in principle offer many opportunities to use ecological information and understanding. Whether these opportunities actually are exploited is a very different question that has significant implications for future research on these methods. Unfortunately, we do not yet know these implications because discussions of the role of information in reduced-chemical production barely go beyond the assertion that it is important. The simple-sounding statement that information can replace material inputs passes over the considerable complexity of the issue. We first must disentangle the various components of information before we can understand the statement. Then we can investigate the circumstances under which information does or does not have an especially important role. That done, we can think about its implications for research strategies.

What do we mean by "information-intensive" agriculture?

The literature on reduced-chemical production methods routinely uses phrases like "information-intensive" in a casual, undiscriminating way that leaves unclear just what is meant. As a result, several distinctions are blurred:

1. Where does information-intensiveness enter: when the system is being developed, or when the farmer uses it?

If the latter, two further questions arise:

2. Is additional information required only for adopting the new system, or also for its continued use?

3. Does dealing with this information simply require devoting additional time

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to it, or does it also demand superior management ability?

These distinctions can be illustrated by various reduced-chemical insect pest control strategies. At one extreme is classical biological control. In its simplest form, once an introduced predator or parasite is released, it establishes itself throughout a region and prevents the pest from ever becoming a problem again. Typically, considerable thought has gone into selecting the control agent, but the farmer may not have to know anything to benefit from it and may not even realize that the introduced organism is what is now controlling the pest (Sailer, 1979).

Where this simple approach is not possible, biological control instead might be incorporated into an integrated system, with other practices adjusted accordingly, sometimes in complex ways (van Lenteren, 1988). Alternatively, no suitable biological control agent might be available. In either case, researchers often must start their development of a reduced-chemical pest management system by studying the behavior of the major pests, the mechanisms that control them naturally, the conditions that determine how much damage they will do, and so forth. The importance of this kind of agroecological foundation for reduced-chemical methods often has been asserted as a general principle, although there has been no systematic study of how strong it actually has been for the methods developed so far. Even where it is important, it is a separate matter from any information-related burden imposed on farmers when the new method is put to use. Regarding the latter, there are several possibilities.

For instance, the agroecological studies might show that a crop variety that matured early would avoid attack by an otherwise severe pest. Cotton provides some impressive examples (Adkisson and Dyck, 1980). In California, the stalks of short-season varieties can be shredded and plowed under before the pink bollworm goes into diapause, which greatly reduces the number that overwinter. In Texas, early varieties offer several advantages: they set fruit before the boll weevil reaches damaging levels; they do not need to be sprayed for protection against late-season attacks of bollworm and tobacco budworm; and they can be plowed under before the boll weevil and the pink bollworm can go into diapause.

As these examples show, agroecological studies can lead directly to a specific recommendation that farmers can easily follow. An understanding of the agroecosystem was necessary for developing the recommendation, but not for using it. For the farmer, increased information is involved only in learning about the recommendation, in deciding to try it, and in learning what other changes might be needed to use the new variety effectively.

In contrast, suppose the agroecological study shows that the seriousness of a particular insect pest varies strongly with weather, the vigor of the crop, and the density of parasites. This means that sometimes no sprays would be necessary. Without these studies the farmer might have used an "insurance" approach: spray, no matter what, to be on the safe side.

To apply this improved agroecological understanding would require an effort by the farmer each year, not just a one-time effort in learning about it. This still leaves two possibilities. It might be possible to reduce the spray/no spray decision to a definite procedure that any farmer could carry out, assuming the time is available. For example, at a specified growth stage of the crop, count larvae on X plots per acre, with Y row-feet per plot. If there are fewer than Z larvae per plot, do not spray. If the procedure can be presented in such a way that anyone can apply it, the use of information means replacing a material input by work, not by skill or judgment.

On the other hand, the decision whether to spray might be more complex, requiring abilities that not all farmers possess. Its information requirements might be very formidable, and not all farmers will be equally good at making the right measurements and keeping adequate records. Perhaps the natural mechanisms that control the pest are not yet understood well enough to allow effective procedures for deciding when to spray, or the procedures are too dependent on site-specific variables to yield reliable recommendations for individual situations. If so, the farmer's experien and understanding become very imp tant. Also, even where there is a standa procedure, an especially astute and c servant farmer can customize it bas on previous experience under that farn particular conditions. Moreover, t might have to be done for each field, even parts of fields.

In summary, the "informatic intensiveness" of a system might re to its development, its adoption, or continued use. Its use might require o straightforward data collection, or might involve especially sophisticat judgment or especially good ability collecting and processing a large amou of information. As shall be discuss later, each of these will have differe implications for agricultural research.

Do reduced-chemical methods require farmers to deal with more information?

Information requirements of reduced-chemical methods currently under research

The remainder of this paper de mostly with the information requi ments of production systems in actu use. However, I first consider the role information as treated in the resear literature on reduced-chemical systen

For a related study (Lockeretz, 199 I examined all research papers reduced-chemical agricultural metho published from 1986 to 1989 in thirte journals. These included eight journa covering the major disciplines, plus t five non-disciplinary journals most like to have relevant papers.

In about one-fourth of these pape (out of 88 for which the question w applicable), to use the reduced-chemic technique the farmer must collect ad tional information and make addition decisions. The most common techniq was scouting for insect pests to deci whether an insecticide was needed. T others involved fertilizers: either i proved soil or tissue testing to elimina overuse, or more careful choice of liv stock manure applications to minimi

the need for inorganic fertilizer. In contrast, only one of 53 papers on conventional techniques specifically involved farmers' use of information.

At least as treated by researchers, therefore, we can say that reduced-chemical systems do deal with information more explicitly. However, this is true only for certain kinds of reduced-chemical methods.

Information needs in adopting a new system

It is not clear how closely the role of information in systems receiving research attention, as just summarized, reflects that of actual farm practices. Because information-intensive production techniques are considered innovative and sophisticated, they probably are more common in research than in practice, whereas more routine techniques probably are underrepresented in the research literature.

Unfortunately, we can only speculate on whether the information requirements of reduced-chemical methods as actually practiced are greater than for other systems. First, consider the farmer's decision to use such techniques. Here, the information requirements do not seem more formidable than for many other decisions that farmers routinely make already.

As an example of a common adoption decision in a conventional operation, suppose the farmer is deciding whether to install an irrigation system. The following are among the factors that must be considered, all of which require much thought and often a substantial amount of new information: the availability, cost, and alternative uses of the needed capital; operating costs, for example for energy, not only at current prices but also allowing for unpredictable inflation over the lifetime of the system; expected average yields and yield variability; labor requirements in comparison with labor availability, especially during periods of peak demand; and possible changes in marketing strategies appropriate to the higher production level. Moreover, the decision to use irrigation cannot be reversed, except by abandoning a large investment, and cannot be tried out on just a few acres. Also, irrigation is a higher-input, higher-output system, so that net return is a smaller fraction of gross revenue. This means there is less room for error; compared to the farmer's current (unirrigated) system, it takes a smaller proportional error in predicted yields or prices to turn a given expected profit into a loss. In contrast, moving toward a reduced-chemical system has the opposite effect; because production costs are lower, the farmer is less highly leveraged, and the effects of an unexpected yield or price decline are somewhat cushioned. For example, assume that expected gross revenue and crop production costs per hectare are, respectively, $400 and $320 without irrigation but $600 and $500 with irrigation. Irrigated production is expected to be more profitable (net of $100/ha compared to $80/ha for unirrigated). However, if the actual crop price turns out 20 percent lower than expected, irrigation loses money ($20/ha), whereas unirrigated production breaks even. Lastly, the need for information does not end with the decision to irrigate; there are many details to settle, such as energy source, type of distribution system, system size, and choice of specific pumps and other components. Also, many changes must be made in other aspects of the production system, such as fertilization, tillage, pest control, and crop mix. These will be major changes at first, followed over the next several years by much fine tuning to the farm's specific conditions.

Adoption of most reduced-chemical methods does not seem more complex than the example just offered. It is true that studies of organic farmers, for example, often report that the lack of adequate information sources is an impediment to wider adoption (e.g., Lockeretz and Madden, 1987). However, adoption of organic farming is a more drastic change than most reduced-chemical alternatives that farmers are now considering. Also, the finding in part may reflect the small amount of research and extension effort given to organic farming so far, rather than the complexity of the system itself. This is another reason that the finding might not be applicable to more familiar, well-studied reduced-chemical alternatives. Excessive emphasis on the information needed for adopting these reduced-chemical methods may unnecessarily discourage potential users. Therefore it is important to learn much more about this question by studying it explicitly and then working to remove the obstacle if it is serious.

Information needed to use various production systems

As already noted, collection of information is a necessary part of certain reduced-chemical methods. Good examples are soil testing and scouting for insect pests. Can we generalize from these clear examples to say that, as a rule, reduced-chemical techniques involve more information than do conventional practices?

Although heavy use of chemicals does overcome certain sources of variation, it does not free the farmer from the need to gather and process information during each growing season. Many of farming's information requirements involve areas other than fertilization and pest control and therefore occur in both conventional and reduced-chemical systems. Also, chemical use does not always mean fixed applications that can be repeated every year regardless of specific conditions, as its detractors sometimes claim.

No matter what the level of chemical use, efficient crop production requires that information be collected throughout each growing season to fine tune the system. Choosing the best crop, planting date, and seedbed preparation method requires close attention to weather at the beginning of the season. During the season, efficient timing of irrigation applications requires frequent monitoring of soil moisture and the condition of the crop. At harvest time, if the crop is to be dried artificially, choosing the best harvesting date means balancing the cost of fuel against field losses (the former is reduced by allowing the crop to dry longer in the field, the latter by harvesting early). This requires careful day-to-day monitoring of the weather and the crop's moisture content.

Clearly, all kinds of farmers continually must gather and process information if they are to run their operations efficiently and profitably. Beyond these ex-

amples, which affect all farmers, reduced-chemical methods do entail certain additional information-related tasks, as previously mentioned. Doesn't this mean that the total information requirements of reduced-chemical systems are greater?

Not necessarily, for two reasons. First, even for farmers who have no special interest in reducing their use of chemicals, information-intensive techniques are available to allow them to use chemicals more efficiently. True, in conventional practice, chemicals sometimes are applied at the highest level that might reasonably be needed, or maybe even higher, as insurance against all contingencies. But the margin between gross revenue and the cost of production often is so narrow that it could be economically ruinous not to take advantage of every technique for selecting the most efficient application rate. Often these techniques are similar to those intended to reduce or eliminate chemical application. For example, computer programs can be very valuable in helping farmers use field observations to decide which insecticide to apply and when to apply it to get the best control; they are not used only to decide if insecticides can be omitted. Similarly, soil testing to learn the economically optimal fertilizer rate in full-chemical systems is done in the same way, and is just as valuable, as when a farmer uses it to know how much to reduce the application rate when an alternative practice has been used, such as a leguminous green manure.

Second, the information requirements of good marketing may be even greater for conventional systems, which often produce larger amounts of fewer commodities. As noted earlier, high-input systems have a proportionally smaller margin between gross revenue and production costs. This means that missing the best price by a given amount cuts more deeply into the profits of a high-input system. Also, when fewer commodities are produced, a poor marketing decision for one is less likely to be offset by a favorable price for another; indeed, buffering against unpredictable fluctuations, both agronomic and economic, is an important appeal of diversified reduced-chemical systems. Optimal marketing of most commodities is very information-intensive. For example, a farmer who produces only cash grains must keep a close watch on changes in commodity futures, supply and demand predictions (both domestic and overseas), availability and cost of grain storage and transportation, and so forth.

A counterargument is that marketing in a reduced-chemical system requires the farmer to collect more information because well-established markets are not available. However, this argument applies only to the small proportion of reduced-chemical products that have a distinct identity in the market, notably certified organic. Most reduced-chemical techniques yield undifferentiated products that get sold the same way as conventional products. As with the earlier point about the lack of adequate information sources for organic agriculture, the particular marketing challenges of organic systems should not be generalized to the larger but less well-defined class of all reduced-chemical systems.

The comparative importance of information in managing conventional and reduced-chemical systems has not been studied, only asserted. Plausible arguments can be made in both directions. The matter warrants careful analysis if we are to develop reduced-chemical alternatives that farmers will accept readily and be able to use effectively.

How important is the variability in farmers' ability to manage information-intensive systems?

In the research literature on reduced-chemical systems, as opposed to anecdotal discussions, when there is an explicit role for information, it involves specific pieces of information and a definite method for using them. Information is incorporated in techniques that any farmer can use, given enough motivation and time. Little attention is usually given to the more intangible matter of the operator's management ability, which is a difficult topic to study. Thus we cannot say whether successful use of a reduced-chemical system requires not just a willingness to put more effort into it, but also a better understanding of the principles governing agricultural systems and a better ability to collect and process in
mation.

Taking a historical perspective,
creased use of chemicals is part of
general transformation of Ameri
agriculture to a more technologically
vanced industrial-style production
tem. This transformation worked v
much to the advantage of farmers v
superior skills and expertise, whe
previously, someone of just average a
ity had a reasonable chance to succ
(Danbom, 1979). Of course, by itself
does not say anything conclusive ab
management of reduced-chemical
tems, for two reasons. First, chem
use is just one aspect of modern agri
tural technology, so that general st
ments about technological developm
do not necessarily apply to chemical
particular. Second, even if the earlier
crease in the use of chemicals did en
more sophisticated management, red
ing their use does not necessarily m
reversing the entire path that agricult
followed when chemicals were adopt
Farmers might be able to cut back
chemicals precisely by becoming m
sophisticated managers (Francis, 19
Still, the historical record places the b
den of proof on those who say t
reduced-chemical systems will req
farmers to be more sophisticated.

The historical record aside, reduc
chemical systems of the future ind
might require superior ability in h
dling information, for various reas
Monitoring one's crops or livestock
quires a sense of what to look for, so
thing that comes from experience
insight. The quantity of informa
needed to manage a system may be
great that only some farmers will be a
to absorb it and use it effectively.
though outside sources of advice (e
magazines, consultants, extension)
available in principle to all farmers, so
farmers are more adept at obtaining s
advice and applying it effectively. A
reduced-chemical systems are said to
more sensitive to environmental v
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wide advice must be adapted to the p
ticular farm, which requires the far
to interpret, evaluate, and integrate
ferent kinds of information (Walter
al., 1990). A related argument is tha

reduced-chemical systems, the components of the production process may interact more closely than in conventional systems. If so, maximizing the positive interactions among the components requires sophisticated understanding. For example, Edwards (1987) argues that "In conventional 'higher-input' farming, high yields can be obtained without appreciable attention to interactions... However, as chemical inputs are lowered progressively, so the need for attention to the mechanism by which one input impacts upon another increases." But we do not know that as actually practiced, reduced-chemical systems really do require a better understanding of interactions among the components of the agroecosystem. Often, in papers that argue strongly that they do as a general principle (e.g., Francis and King, 1988; Pimentel et al., 1989), the examples of actual reduced-chemical approaches are discrete techniques that can be selected individually, without being integrated into any kind of "system." Also, as Harwood (1985) has commented, even though the structure needed to get the desired interactions among components may be complex, "many of the effects are common to well-structured systems... [Therefore] total information...is not necessary to their implementation."

Discussions of farmers' experiences in managing reduced-chemical systems are largely anecdotal. Often they concern organic farming or other systems with heavily reduced chemical use, rather than more moderate changes. Case study authors often comment on their subjects' excellent management ability. Assuming this assessment is correct, this ability might be required only while the unconventional system is being used by a small minority of farmers who largely must fend for themselves, with little assistance from established sources of advice. But if superior management ability will be needed even with higher levels of adoption, this has important implications for wider acceptance of such methods. Emphasis on organic farmers' management skills helps counteract the unfortunate stereotype that farmers who prefer not using modern chemicals are backward or unsophisticated. Supporters of reduced-chemical methods like to say that low chemical use does not mean low-caliber management. This makes such systems more attractive, which is important because farmers are notoriously sensitive to what other people think of their operations. An interesting parallel is that from the earliest days of the experiment station system, an expected indirect benefit was that when farming methods involved more knowledge, skill, and scientific understanding, this would raise the public's image of farmers as professionals (Danbom, 1986).

However, emphasis on management sophistication might backfire by scaring off farmers who fear that the required skills might be excessive. Recognizing this, Coleman (1985), in contrast to most supporters of reduced-chemical systems, advocates breaking them down into discrete elements that readily can be mastered by any farmer. Whether this is possible without seriously compromising their essential character is a question that no doubt will arouse strong controversy.

Implications for research

Prevailing research approaches are not well suited for agricultural systems that depend strongly on how well the farmer can handle information. If this ability is dealt with at all, it usually is treated separately from the biological and agronomic aspects of the system. Typically, it enters at the demonstration and extension phase, after the system has been developed and evaluated.

This can be a serious shortcoming. In typical protocols the experimental treatments are chosen in advance, whereas reduced-chemical systems are commonly thought to require flexibility in adjusting to conditions during the growing season, such as weather, weed pressures, and insect densities. For example, the farmer might cultivate an extra time if weed problems are exceptionally severe. (Of course, farmers also make similar adjustments within conventional systems.) When such a system is in actual use, it is the farmer, not the researcher, who will have to decide on these adjustments. But the greater the importance of farmers' management skills and decision-making ability for the system's success, the harder it is for researchers to evaluate the system realistically and the greater the likelihood of errors in extrapolating from the experimental setup to working farms.

The problem is well illustrated by studies of organic farming. Besides not using conventional pesticides and fertilizers, organic systems typically differ from prevailing practices in many other ways, such as their more diversified crop rotations, greater reliance on livestock manure, and more frequent use of legume cover crops or green manures. Because of practical limitations, it would be impossible to run a multi-factorial experiment in which all these differences are studied simultaneously, with all their interactions, to allow a simulation of the whole to be constructed from the components. Comparative evaluations of organic and conventional systems, therefore, must deal with each system as a whole. This includes studying the farmer, especially because in reduced-chemical systems such as organic farming, the farmer's adjustments to changing conditions are considered critical.

How should such a study be done? The results will be a more valid measure of the system's performance if the experiment permits responsiveness to conditions during the growing season. However, in a multiyear study, statistical problems may arise if treatments are varied from year to year. The usual analysis methods work best with fixed treatments chosen in advance; they do not readily handle many kinds of "mid-course corrections." Even more important is the question of how to decide these adjustments, which are considered to require judgment and intuition. This makes such a study different from one involving an objective decision-making procedure, for example a computerized pest management model that recommends whether an insecticide should be applied. There, the actual application is also unknown beforehand, but the method by which it will be chosen has been fixed. But organic farming and other systems with strongly reduced use of chemicals cannot yet be managed by the book. Therefore, how the adjustments are decided, and by

whom, are additional sources of experimental variation.

This means that research must learn to deal realistically with farmers' varying ability to handle information in systems where it is considered especially critical. If this ability can replace some chemical applications, it merits a place in the experimental protocol comparable to that of chemical applications. Sometimes this presents no great problem. For example, in developing and validating expert systems to aid farmers' pest management decisions, one can readily study whether farmers would be willing to use the system and, if so, whether they can use it properly. In contrast, for decisions that involve more intuition and judgment, the human element cannot be taken into account as precisely. At least it should be included as a confounding variable, similar to weather or soil type. Standard experimental procedures average out the effects of the latter variables, but management ability simply does not get into most research on new production methods.

Giving management ability its appropriate place will not be easy. Presumably, it will require that a larger share of research be done on working farms; farmers' judgment does not seem like something that researchers should try to simulate. This means that working farmers should be part of the research earlier than is now customary, instead of being considered only after the research itself has been completed and the techniques are ready to be moved off the experiment station.

Also, it might be fruitful to distinguish clearly between two kinds of studies that are not always kept distinct: those that seek to evaluate how well a system works and those that seek to explain why it works the way it does. Both purposes are valid, but they usually will require different kinds of studies (Lockeretz, 1985). If we want to learn how well a system works, we should study the system, not an artist's conception. In particular, if adjustments during the growing season are an intrinsic part of the system, these should be allowed in the research. On the other hand, if we wish to learn the details of a particular relationship, then keeping certain practices fixed, even though it is unrealistic, might be essential for controlling "irrelevant" variation. Of course, the results of such work should not also be taken as showing how good a particular system is, if what was studied was not a reasonable embodiment of that system.

Experiment stations often will be more suitable for explanatory studies, whereas working farms seem especially appropriate for evaluative work. Also, the latter should be done on more than one farm to get variation both in growing conditions and in farmers' management ability and decision-making styles. If the prevalent view of reduced-chemical systems is correct, judgment and insight are sufficiently important that even good farmers might make different decisions given the same information.

Information and decision-making ability: Essential elements of all agricultural production systems

The issues just discussed are not unique to reduced-chemical systems. Sometimes different kinds of information will be needed, but the success of any production system demands that the farmer constantly gather and think about new information. Any difference with reduced-chemical systems is one of degree.

True, information and decision making are talked about especially often for reduced-chemical systems. However, we must not conclude too much just from what people say; very likely, the role of information and decision making in conventional systems has been understated. Some discussions not only emphasize their positive role in reduced-chemical systems, but also imply that chemicals somehow make them unnecessary in conventional systems.

This is a serious oversimplification. As an example, consider soil testing to improve the choice of N fertilizer application rate, as described earlier. Because of year-to-year variations in available N from a leguminous green manure or livestock manure, in-season soil testing is particularly valuable in reduce chemical systems. Often it will show th little or no fertilizer is needed, where the farmer otherwise might have appli fertilizer excessively to avoid the ri that total available N was inadequa However, even if the farmer uses or inorganic fertilizer, soil testing can det mine the most economical applicati rate. This would not qualify as reduced-chemical system; the soil t will sometimes lead to an increase in application. However, the type of info mation and decision making is the sam

The main difference may be that f reduced-chemical systems, informatio is consciously thought of as a systemat way of replacing material inputs. In co trast, in a conventional system it simp may not be considered as deserving sp cial comment. (This may be true eve for reduced-chemical research; Willia Liebhardt, in refereeing this paper, note that research articles on reduce chemical systems often do not discu the thinking that went into their deve opment.)

This is a serious omission. No agricu tural system, whatever its use of chem cals, can be developed to its full potenti if intangible inputs like information a not given just as careful thought as mat rial inputs. The talk about th information-intensiveness of reduce chemical agriculture should serve to r mind us of that, even if it correspond only imperfectly to the realities reduced-chemical production practic and research. The most important cons quence of such talk could be that makes us take a new look at an issu that is important in research on ever agricultural system, but which we som times have shortchanged. If so, its valu will reach far beyond the contribution makes to the development of reduce chemical techniques in particular.

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BOOK REVIEWS

Enduring Seeds: Native American Agriculture and Wild Plant Conservation. 1989. By Gary Paul Nabhan. North Point Press, San Francisco, California. 225 pp. $18.95, hardcover.

While the importance of genetic preservation has received considerable attention in recent years in both the popular and scientific presses, Gary Nabhan explores the topic of plant conservation from several interesting perspectives. He focuses on plant conservation in diverse geographic regions of North America instead of the tropics, where much of the recent research on species loss has been conducted. Plant species discussed by Nabhan include wild rice, sugar cane, chiles, squash, gourds, sunflowers, corn, and beans, as well as some lesser known Native American crops like little barley, grain amaranth, hackberries, sump weed, water chinquapin, and a species of cotton. A unique feature of Nabhan's work is his focus on the historical value of plants and animals rather than the potential economic benefits of threatened species. Perhaps most significantly, Nabhan, an ethnobiologist, views seeds as cultural symbols and investigates the role of such symbols in agricultural sustainability.

In the prologue to *Enduring Seeds*, Nabhan demonstrates both the relative scarcity and fragility of domesticated plants native to this continent. "Cupping my two hands together, I can hold a single seed of each plant that grows on the acres of desert lands where I live. Filling a bottlegourd canteen full with one seed from each genetically-distinct cultivated variety native to this continent, I could also carry around samples of all of the domesticated crop strains known to have existed prehistorically in North America." He draws an interesting comparison between the sacred lotus native to Asia and the common bean native to North America. The wild lotus has a tough seedcoat which requires considerable physical manipulation for germination to occur, while the seedcoat of the bean, domesticated eight to ten thousand years ago by Native Americans, is fragile. Even when stored in optimum conditions, it is difficult to maintain germplasm viability beyond twelve years unless the seed is refrigerated. It is believed that the bean once had a seedcoat (like that of the lotus) which offered excellent protection against its primary natural enemy, the bruchid beetle. Through nomadic activity and trading with other tribes, domesticated bean seeds were dispersed into areas devoid of beetles. No longer needing to discourage seed penetration, the domesticated bean lost the tough seedcoat needed to maintain seed viability under adverse conditions. According to Nabhan, human intervention has caused the domesticated bean to lose its ability to survive in the wild, and therefore the survival of the bean as a species is tied to our willingness to maintain its cultivation.

Nabhan does an effective job of demonstrating Native Americans' knowledge of the importance of genetic diversity. By speaking with Native American farmers in Mexico and in the American Southwest, Nabhan learned that farmers physically separated the various varieties of corn they grew. Instead of allowing distinct varieties to merge over the years into a single strain of corn which would be susceptible to epidemics of disease and insects, farmers spread their risk around over many corn varieties. Nabhan maintains that Native American farmers would periodically use these "gene reserves" to introduce to one corn variety some beneficial characteristic found in another.

Nabhan reminds us that nearly all of today's modern commercial corn varieties are descended from the same parent stock. Infusing these commercial varieties with disease resistance or another beneficial characteristic not found in current genetic stocks is possible only if new corn varieties which

contain these genes can be found in the wild. The need for new germplasm is why the discovery of wild corn varieties in Mexico and South America caused such excitement in the commercial corn industry in recent years.

Nabhan devotes a considerable portion of *Enduring Seeds* to the topic of gene banks. While many scientists believe the best way to counter the erosion of our genetic base is to maintain germplasm in cold storage, Nabhan questions the wisdom of placing all our hope, and all our seeds, in gene banks. While he is not against the use of cold storage facilities, he is against the use of gene banks as the sole means of preserving genetic material.

Nabhan proposes three key reasons why a primary reliance on gene banks might be a mistake. First, he claims that gene bank technology is relatively new. No one knows how long seeds will remain viable in them, especially the more fragile seeds like beans. Gene banks also require a complex infrastructure that might not survive natural disasters or periods of social unrest. Secondly, gene banks typically store many varieties taken from a small number of economically valuable species; this contributes to the potential loss of species which have limited present value but which might prove of enormous economic value in the future. And thirdly, Nabhan is concerned with limited evolutionary capacity. Plants grown from seeds stored in gene banks may be reintroduced into a world that contains pests against which they have not developed resistance.

Along with gene banks, Nabhan advocates the use of living reserves where plants maintain the ability to evolve defenses against naturally occurring pests. These living reserves do not require a complex infrastructure; indeed, individuals have demonstrated the ability to develop and maintain them in private collections. This activity will be supported and fostered with the creation of organizations like Native Seeds/SEARCH and Seed Savers Exchange.

A central theme which weaves its way through nearly all of Nabhan's arguments in *Enduring Seeds* is the premise that agricultural sustainability is possible only when a culture views genetic diversity as a cultural symbol, not just as an economic benefit. He writes about many religious ceremonies which have as their basis the celebration of plants or animals essential to a people's agriculture, and Nabhan maintains that these symbols encourage the wise use of genetic resources.

Nabhan is a clever writer. He is also a respected scientist and dedicated activist. These qualities unite in *Enduring Seeds* and result in a book which is timely, stimulating, and accurate. Because the twelve essays in this collection are based on public lectures and articles written for periodicals, it is important to give this book more than one reading. What at first glance appears as fragmentation is instead a rich and complex literary mosaic woven fro various crop varieties, geographi areas, and historical periods. This mo saic demonstrates that genetic prese vation leads to sustainability and tha cultural values are key determinants i how successfully the genetic base of ag ricultural crops is preserved.

Unfortunately, readers of *Endurin Seeds* may be left with a keen interes in halting the genetic erosion of Nativ American crops but without a sense o how it might be accomplished. How ever, to Nabhan's credit, this work doe create in the reader a desire for mor information about the subject of plan conservation--perhaps the greates praise a book of this nature can receiv -- *Mark A. Lelle, Director, Albion Civ Life Project, Albion, MI.*

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test and validate these relationships is to use the necessary time and space. Full-scale demonstrations are also critical tools in gaining public and governmental acceptance of new approaches.

As described at the conference by staff from EPA's Office of Technology Transfer and Regulatory Support, EPA currently funds about $9 million of agriculturally related research. However, EPA does not have a centrally planned and integrated agricultural research program. Rather, a number of separate research projects address the specific information needs of different policy offices. Current research topics include the effects of agricultural chemicals on ground water; risk assessment methods for new biotechnology products; human health effects of agricultural chemicals; and effects of global climate change on crops.

New and proposed EPA research programs offer a more integrated approach and greater emphasis on sustainable agriculture. The Environmental Monitoring and Assessment Program (EMAP) is developing indicators and procedures for assessing trends in the condition of agroecosystems at regional scales. The Midwest Agrichemical Surface/Subsurface Transport and Effects Research (MASTER) project is collaborating with the USDA/USGS M continent Water Quality Initiative. EI focuses on determining the ecological fects of conventional and alternati agriculture at the landscape scale. EI is also developing a proposal for jo research with USDA in 1993 on in grated farm management systems.

EPA's future contributions to search on sustainable agriculture a agroecology will be small relative those of USDA and other funding ag cies. EPA will need to leverage its effo with those of other groups in order have a significant impact. The Susta able Biosphere Initiative (SBI), dev oped by the Ecological Society America (ESA), was presented dur the conference as one possible fra work for facilitating collaborative search on agroecology. The SBI rep (Ecology 72(2):371-412) identifies pri ities for research on sustainable ecolo cal systems and recommends steps implementing an ecological resea program.

Note: A conference proceedings w be published. For information cont Richard Olson, ManTech Environm tal Technology, Inc., USEPA Envir mental Research Laboratory, 200 S 35th, Corvallis, OR 97333.

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The American Journal of Alternative Agriculture (AJAA) ublishes original research on biological, physical, or social ience aspects of alternative agriculture. We particularly wel- ome multi-disciplinary studies, but papers from a specific iscipline also are invited. However, since AJAA readership much broader than for a single-discipline journal, highly ecialized terminology should be explained or avoided. The gnificance of a statement, or the reasoning behind a con- usion, may have to be spelled out more than in a more ecialized journal. See Vol. 5, No. 1, pp 2 & 3, for an xplanation of the various categories of articles.

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Research papers should use the International (SI, or metric) ystem throughout. Occasional use of common unit equiva- nts in parentheses is permitted, mainly for relatively exotic units.

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The title page should give the following information (all ush left): 1) title of the paper; 2) names of authors; 3) af- liation and office address of authors, and 4) acknowledge- ents, if any. See examples in this issue of AJAA.

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Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

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The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

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Submit four high-quality copies to Editor, American Journal of Alternative Agriculture, Suite 117, 9200 Edmonston Road, Greenbelt, MD 20770. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form; that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

Low-input alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization set up in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

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